EAST Search History

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	469	helical wound and hollow fiber and membrane	USPAT; EPO; DERWENT	AND	ON	2006/05/03 13:32
L2	34	1 and core same permeable	USPAT; EPO; DERWENT	AND	ON	2006/05/03 13:32
L3	0	2 and "metal beads" same core	USPAT; EPO; DERWENT	AND	ON	2006/05/03 13:33
L4	0	2 and "metal beads"	USPAT; EPO; DERWENT	AND	ON	2006/05/03 13:33
L5	8	2 and fibers same spacing	USPAT; EPO; DERWENT	AND	ON	2006/05/03 13:43
L6	8	5 and fibers same spacing	USPAT; EPO; DERWENT	AND	ON	2006/05/03 13:43
L7	6	5 and "fibers spacing"	USPAT; EPO; DERWENT	AND	ON	2006/05/03 13:59

EAST Search History

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	469	helical wound and hollow fiber and membrane	USPAT; EPO; DERWENT	AND	ON	2006/05/03 13:32
L2	34	1 and core same permeable	USPAT; EPO; DERWENT	AND	ON	2006/05/03 13:32
L3	0	2 and "metal beads" same core	USPAT; EPO; DERWENT	AND	ON	2006/05/03 13:33
L4	0	2 and "metal beads"	USPAT; EPO; DERWENT	AND	ON	2006/05/03 13:33
L5	8	2 and fibers same spacing	USPAT; EPO; DERWENT	AND	ON	2006/05/03 13:43
L6	8	5 and fibers same spacing	USPAT; EPO; DERWENT	AND	ON	2006/05/03 13:43
L7	6	5 and "fibers spacing"	USPAT; EPO; DERWENT	AND	ON	2006/05/03 13:59
L8	21709	hollow fiber and core	USPAT; EPO; DERWENT	AND	ON	2006/05/03 14:00
L9	0	8 and core same polyethelene and sintered	USPAT; EPO; DERWENT	AND	ON	2006/05/03 14:01
L10	0	"sintered polyethylene beads" and core and hollow fibers	USPAT; EPO; DERWENT	AND	ON	2006/05/03 14:02
L11	3663	core material and membrane and hollow fibers	USPAT; EPO; DERWENT	AND	ON	2006/05/03 14:02
L12	0	11 and "polyethylene beads" same sintered	USPAT; EPO; DERWENT	AND	ON	2006/05/03 14:03
L13	0	11 and "polyethylene beads"	USPAT; EPO; DERWENT	AND	ON	2006/05/03 14:03
L14	168	sintered polyethylene and 11	USPAT; EPO; DERWENT	AND	ON	2006/05/03 14:03
L15	31	14 and core same polyethylene	USPAT; EPO; DERWENT	AND	ON	2006/05/03 14:17

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DOCUMENT-IDENTIFIER: US 6004511 A

TITLE: **Hollow fiber** oxygenator

DATE-ISSUED: December 21, 1999

INVENTOR-INFORMATION:

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APPL-NO: 09/029646

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FOREIGN-APPL-PRIORITY-DATA:

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DE	195 32 365	September 1, 1995

PCT-DATA:
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INT-CL-CURRENT:

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CIPS	A61M1/16	20060101
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US-CL-ISSUED: 422/45 , 422/44 , 422/46

US-CL-CURRENT: 422/45, 422/44 , 422/46

FIELD-OF-CLASSIFICATION-SEARCH: 422/44; 422/45 ; 422/46
See application file for complete search history

REF-CITED:

U.S. PATENT DOCUMENTS

PAT-NO	ISSUE-DATE	PATENTEE-NAME	US-CL		
3422008	January 1969	McLain	N/A	N/A	N/A
3794468	February 1974	Leonard	N/A	N/A	N/A
4031012	June 1977	Gics	N/A	N/A	N/A
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EAST Search History

L16	8	15 and polyethylene same sintered	USPAT; EPO; DERWENT	AND	ON	2006/05/03 14:06
L17	2	16 and beads	USPAT; EPO; DERWENT	AND	ON	2006/05/03 14:04

N/A

5830370	November 1998	Maloney et al.	210/780
N/A	N/A		

FOREIGN PATENT DOCUMENTS

FOREIGN-PAT-NO	PUBN-DATE	COUNTRY	US-CL
93677	March 1983	EP	
0 089 122	September 1983	EP	
0 187 708	August 1992	EP	
1470075	April 1977	GB	
1481064	July 1977	GB	
1500945	May 1978	GB	

ART-UNIT: 372

PRIMARY-EXAMINER: McDermott; Corrine

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ATTY-AGENT-FIRM: Cumberbatch; Guy Vinitskaya; Lena I.

ABSTRACT:

A **hollow fiber** oxygenator includes a housing defining a blood chamber between an inner **core** wall and an outer wall. The chamber includes at least one blood inlet and at least one blood outlet. A plurality of **hollow** semi**-permeable fibers** extend through the chamber. Each **fiber** has an open inlet and and an open outlet end, the ends being sealed from the chamber by sealings. The oxygenator further includes a gas inlet on one end of the chamber in communication with the inlet ends of the **fibers,** and a gas outlet on the other end of the chamber in communication with the outlet ends of the **fibers**. Blood flows into the chamber and across the exterior surfaces of the **fibers** to effectuate gas transfer therebetween. A partitioning wall divides the chamber into at least two sections. In one of the sections, the blood flow is co-current with the gas flow, while in another section the blood flow is counter-current with respect to the gas flow. The chamber may be annular and the partitioning wall tubular, with a first section being concentrically disposed within a second section. Desirably, blood flows in the first section counter-current with respect to the gas flow, across a flow passage way, and flows in the second section co-current with respect to the gas flow. The **hollow fibers** may be provided in layers with the **fibers** in each layer being parallel, and the **fibers** in adjacent layers being angled with respect to each

other and with respect to the axis of the housing.

29 Claims, 5 Drawing figures

Exemplary Claim Number: 1

Number of Drawing Sheets: 5

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Abstract Text - ABTX (1):

A **hollow fiber** oxygenator includes a housing defining a blood chamber between an inner **core** wall and an outer wall. The chamber includes at least one blood inlet and at least one blood outlet. A plurality of **hollow** semi**-permeable fibers** extend through the chamber. Each **fiber** has an open inlet and and an open outlet end, the ends being sealed from the chamber by sealings. The oxygenator further includes a gas inlet on one end of the chamber in communication with the inlet ends of the **fibers,** and a gas outlet on the other end of the chamber in communication with the outlet ends of the **fibers**. Blood flows into the chamber and across the exterior surfaces of the **fibers** to effectuate gas transfer therebetween. A partitioning wall divides the chamber into at least two sections. In one of the sections, the blood flow is co-current with the gas flow, while in another section the blood flow is counter-current with respect to the gas flow. The chamber may be annular and the partitioning wall tubular, with a first section being concentrically disposed within a second section. Desirably, blood flows in the first section counter-current with respect to the gas flow, across a flow passage way, and flows in the second section co-current with respect to the gas flow. The **hollow fibers** may be provided in layers with the **fibers** in each layer being parallel, and the **fibers** in adjacent layers being angled with respect to each other and with respect to the axis of the housing.

TITLE - TI (1):

Hollow fiber oxygenator

Brief Summary Text - BSTX (2):

The present invention relates to a **hollow fiber** oxygenator, a specific **hollow fiber** arrangement and a method for oxygenating blood.

Brief Summary Text - BSTX (5):

EP-A-0 089 122 discloses a **hollow fiber** blood oxygenator having a mat of a

plurality of contiguous **fiber** layers around a porous core, wherein contiguous **fiber** mat layers exhibit an angle of divergence from the longitudinal axis of the core, wherein the sense of divergence changes in every layer. The blood flows radially across the **fiber** mat. The **fibers** do not substantially fill the whole of an annular chamber around the core.

Brief Summary Text - BSTX (6):
EP-B-0 187 708 discloses a **hollow fiber** blood oxygenator, wherein **fibers** or small **fiber** ribbons are **wound** helically around a core, wherein a first plurality of **fibers is wound** in one sense and a second plurality of **fibers is wound** in the other sense similar to a yarn winding operation. The blood flows axially through the **fiber** windings, which occupy substantially all of an annular chamber around the core. Gas flow and blood flow may be counter-current.

Brief Summary Text - BSTX (7):
U.S. Pat. No. 4,239,729 discloses a **hollow fiber** blood oxygenator, wherein **fibers** are arranged axially in an elongated housing and do not substantially fill the housing. Blood flows through the **fibers** whereas the oxygenating gas flows radially with respect to the **fibers**.

Brief Summary Text - BSTX (8):
U.S. Pat. No. 3,422,008 discloses a **hollow fiber** blood oxygenator and a method for forming it, wherein **hollow fibers** are helically **wound** on the core in such a way that intermediate **helical** windings are reversed. Thus, successive layers have opposite winding sense with respect to the, core axis. The blood flow is radial. The annular space is not substantially filled with the **fibers**.

Brief Summary Text - BSTX (9):
U.S. Pat. No. 4,031,012 discloses a separatory apparatus which can be used as an oxygenator comprising a card-shaped core on which **hollow fibers are wound** either parallel to the core, having an angle to the core axis, or having a cries-cross arrangement or zigzag arrangement with respect to successive layers in which the angle is reversed. A counter-current flow of blood and oxygen is preferred, wherein the blood flows outside the **hollow fibers**.

Brief Summary Text - BSTX (10):
GB-1 481 064 discloses a **membrane** apparatus which may be an oxygenator having **hollow fiber** bundles being contained in a receptacle but not substantially filling it. An angle of 10 to 40.degree. may be formed between adjacent layers of **fiber** bundles. The fluid flow is principally radial.

Brief Summary Text - BSTX (11):
U.S. Pat. No. 4,141,835 discloses a dialysis apparatus, wherein a number of separated **fibers** are arranged in a straight line in a housing. The housing is not filled with the **fibers** which may also be arranged in **helical** lines. A fluid flows axially outside the **fibers**.

Brief Summary Text - BSTX (12):
EP-A-0 093 677 discloses an apparatus which can be used as an oxygenator in which rolled mats of **fibers** are arranged, in which the **fibers** may be crossed in an angle between 1 and 5.degree.. The blood flows in the **fibers**.

Brief Summary Text - BSTX (13):
The known **hollow fiber** oxygenators exhibit a number of disadvantages depending on their construction. They are bulky, have a short blood flow path through the oxygenator and have, thus, a small contact zone for the blood and the gas and consequently a short residence time for the blood in the oxygenator which leads to a poor gas exchange rate. Blood and gas pressure drops may occur as well as channeling of blood or stagnation of blood in certain areas of the contact zone between blood and gas.

Brief Summary Text - BSTX (16):
A further object of this invention is to provide a blood oxygenator which is of simple construction, allowing in particular a simple arrangement on and application to a core of **hollow fibers**.

Brief Summary Text - BSTX (21):
In accordance with this invention a **hollow fiber** oxygenator is provided, which comprises a housing, comprising

Brief Summary Text - BSTX (25):
selectively permeable continuous **hollow fiber** filaments extending inside the chamber between the first cap and the second cap,

Brief Summary Text - BSTX (26):
wherein the ends of the **fibers** are sealed between the core wall and the outer wall at the ends of the chamber spaced from the caps, thus leaving a header space between the sealings and the caps, the ends of the **fibers** being open,

Brief Summary Text - BSTX (27):
wherein the circumferential angle difference for the **fibers** between the two sealings is between 0.degree. and 180.degree..

Brief Summary Text - BSTX (28):
In a preferred embodiment, the **fibers** are arranged in a first plurality of **fibers** and in a second plurality of **fibers,** wherein the first plurality of the **fibers** and the second plurality of the **fibers** have the same directional sense but different circumferential angle differences, the length of the **fibers** of the first plurality of **fibers** being different from the length of the **fibers** of the second plurality of **fibers**.

Brief Summary Text - BSTX (29):
In prior art devices the **fibers have been wound** around the core in a technique similar to winding yarn on a bobbin (continuous rotation of the core coupled with oscillating axial movement of the **fiber** guide also known as cross winding). Thereby the circumferential angle difference of a given **fiber** between the two sealings was always well above 360.degree., frequently involved several full rotations, i.e. multiples of 360.degree.. This prior art procedure had the disadvantage that a wrapping process and thus very long **fibers** between the sealings was required. The present invention avoids this drawback and allows the use of much shorter **fibers** as well as a simpler production of the oxygenator.

Brief Summary Text - BSTX (30):
Furthermore in accordance with this invention a **hollow fiber** oxygenator is provided, which comprises a housing, comprising

Brief Summary Text - BSTX (33):
first and second caps closing the chamber at a first and, respectively, a second end thereof, one of the caps having at least one gas inlet, the other having at least one gas outlet associated therewith, selectively permeable continuous **hollow fiber** filaments extending inside the chamber between the first cap and the second cap,

Brief Summary Text - BSTX (34):
wherein the ends of the **fibers** are sealed between the core wall and the outer wall at the ends of the chamber spaced from the caps, thus leaving a header space between the sealings and the caps, the ends of the **fibers** being open,

Brief Summary Text - BSTX (36):
By the specific arrangement of the **fibers** and/or the partitioning wall the residence time of the blood inside the oxygenator is increased, thereby improving the gas exchange rate of the oxygenator. By the specific orientation

of the **fibers** inside the oxygenator a longer flow path of the blood is achieved which results in a better gas transfer, a longer residence time and thus a smaller construction size of the whole oxygenator arrangement while retaining the same performance or even improved performance. With the specific arrangement of the **fibers** and the blood flow path through the oxygenator no channeling of blood occurs, areas of blood stagnation are avoided and the pressure drop for the blood is rather low, thus allowing a treatment of the blood under moderate conditions which prevent or reduce the damage of the components of the blood. The specific arrangement of **fibers** allows a very simple construction of the blood oxygenator, especially a very simple arrangement of the **fibers** around the core of the oxygenator.

Drawing Description Text - DRTX (6):
FIG. 4 is a perspective view of a **hollow fiber** arrangement according to the present invention; and

Drawing Description Text - DRTX (7):
FIG. 5 is a perspective view of a **hollow fiber** arrangement according to the present invention showing the blood flow path through the **fiber** filaments and gives an illustration of the definitions of **fiber** directions.

Detailed Description Text - DETX (14):
Hollow Fibers

Detailed Description Text - DETX (15):
The **hollow fibers or hollow fiber** filaments used in this invention ma be any **fibers** that are selectively permeable and have continuous lumen therethrough.

Detailed Description Text - DETX (16):
The **fibers** are preferably made of polypropylene which has been modified by silicones or other types of polymers.

Detailed Description Text - DETX (17):
The **hollow fiber** filaments may have any desirable diameter, with an outer diameter of from 365 to 400 .mu.m preferred, from 365 to 380 .mu.m being especially preferred. Useful **hollow fiber** filaments are commercially available from AKZO and CELANESE companies and under the name oxiphan and celgard, respectively.

Detailed Description Text - DETX (18):
Another preferred **hollow fiber** is a microporous polypropylene **hollow fiber** with an inner diameter of 50 .mu.m, an external diameter of 280 .mu.m, an

average pore size of 0,04 .mu.m and a porosity of 50%.

Detailed Description Text - DETX (19):
Hollow Fiber Arrangement

Detailed Description Text - DETX (20):
In the embodiment of FIG. 3, the selectively **permeable** continuous **hollow fiber** filaments 44 extend inside the chamber 28' between the first cap 36 and the second cap 38. In a preferred embodiment the **hollow fibers** 44 substantially fill the chamber 28' between the **core** wall 24' and the outer wall 26'.

Detailed Description Text - DETX (21):
The ends of the **fibers** 44 are sealed between the core wall 24' and the outer wall 26' at the ends 46, 48 of the chamber spaced from the caps 36, 38, thus leaving a header space 50, 52 between the sealings 46, 48 and the caps. The ends of the **fibers** 44 are open, so that gas may flow from the gas inlet 40 of one of the caps through the **fibers** and finally through the gas outlet 42 in the other cap.

Detailed Description Text - DETX (22):
In the preferred embodiment depicted in FIG. 1 the **fibers** are arranged in the chamber in such a way that the circumferential angle difference for the **fibers** between the two sealings is between 0.degree. and 180.degree.. The term "circumferential angle difference" describes the angle through which the core must be turned around its longitudinal axis in order to arrive from one sealing of the **hollow fiber** to the other sealing of the **hollow fiber**. It may also be described as the angle between the projections of the longitudinal axis of the core, the first sealing point of the **fiber** and the second sealing point of the **fiber** into a plane which is perpendicular to the longitudinal axis of the core. FIG. 5 illustrates the term "circumferential angle difference", which is the included angle 41.degree..

Detailed Description Text - DETX (23):
This circumferential angle difference is between 0.degree. and 180.degree. for the **fibers,** preferably between 0.degree. and 90.degree..

Detailed Description Text - DETX (24):
As seen in the detail of FIG. 4, the **hollow fibers** are divided into a first plurality of **fibers** 60 and a second plurality of **fibers** 62. Both pluralities of **fibers** have the same directional sense with respect to the circumferential angle difference formed by them, but they have different circumferential angle

differences. This means that the path of one of the pluralities of **fibers** from one sealing to the other sealing is steeper than the path of the other plurality of **fibers**.

Detailed Description Text - DETX (25):
Furthermore, the length of the **fibers** of the first plurality of **fibers** 60 is different from the length of the **fibers** of the second plurality of **fibers** 62. This is a result of the path of one of the plurality of **fibers** being steeper than the path of the other plurality of **fibers**. Thus, one plurality of **fibers** has a longer path from one sealing to the other sealing thus forming a different length of this plurality of **fibers** from the other plurality of **fibers**. Preferably, the filaments in each of the plurality of **fibers** are parallel to each other and pass from one sealing to the other sealing substantially without any additional curves or bends. In this way the steeper plurality of **fibers** necessarily has a smaller length between the sealings than the less steep plurality of **fibers**.

Detailed Description Text - DETX (26):
With a circumferential angle difference of 0.degree. the **fiber** filaments extend principally parallel to the longitudinal axis of the core from one sealing to the other sealing. With a circumferential angle difference of 180.degree. the **fibers** pass halfway around the core on their way from one sealing to the other sealing. Thus, none of the **fibers** passes more than halfway around the core of the oxygenator chamber.

Detailed Description Text - DETX (27):
In the oxygenators according to the state of the art usually a plurality of **fibers is wound** around the core in a **helical** fashion. At the end of the core the winding direction is reversed but the winding sense is maintained. Thus, the winding of the **fibers** on the core is similar to a yarn winding operation wherein the yarn is passed up and down on the turning core on which it is **wound**. This manner of winding **fibers** around the core has several restrictions: each **fiber** must be **wound** around the core several times in order to fix it to the core. Thus, usually the circumferential angle difference for the **fibers** between the sealings is a multiple of 360.degree.. This large circumferential angle difference is necessary to fix the **fibers** on the core when the winding direction of the **fiber** is reversed at the end of the core. Otherwise, the **fibers** would fall off the core. The reversal of the winding direction but not of the winding sense leads necessarily to an arrangement of **fibers** in which (after cutting the **fibers** in the region of the sealings) one plurality of the **fibers** has one directional sense on the core and one circumferential angle difference and a second plurality of **fibers** has the opposite directional sense

around the core and the same circumferential angle difference but in the opposite directional sense.

Detailed Description Text - DETX (28):
Consequently it is not possible to arrange **fibers** around the core with a circumferential angle difference being less than 180.degree. (for practical reasons not less than at least several hundred degrees). Furthermore, it is not possible that two pluralities of **fibers** have the same directional sense but different circumferential angle differences since the arrangement of the second plurality of **fibers** is just the reversed arrangement of the first plurality of **fibers,** thus always leading to the same circumferential angle difference but different directional senses.

Detailed Description Text - DETX (29):
As a consequence the **hollow fiber** arrangement according to the first embodiment of the present invention cannot be obtained by rotating the core and winding the filaments from a continuous roll of filaments onto the core by reversing the feed direction of the filament at the top and bottom ends of the core, since this process for manufacturing the **fiber** mat is only applicable when the second plurality of the **fibers are wound** in the other sense with respect to the first plurality. In a preferred embodiment of the present invention the circumferential angle differences of the first plurality of **fibers** 60 and the second plurality of **fibers** 62 differ by at least 5.degree..

Detailed Description Text - DETX (30):
The direction of the **fibers** around the core may be further described by the inclination angle between the **fiber** filaments and the longitudinal axis of the core. If this inclination angle amounts to 0.degree., the **fiber** filaments are principally parallel to the longitudinal axis of the core. When this angle is 90.degree., the **fibers** run around the core in one plane each with which is perpendicular to the longitudinal axis of the core. According to a first embodiment of the present invention the preferably parallel **fibers** of the first plurality of **fibers** 60 have an inclination angle with the longitudinal axis of the core of less than 90.degree. and the preferably parallel **fibers** of the second plurality of **fibers** 62 have an inclination angle with the longitudinal axis of the core of between 0.degree. and the inclination angle of the **fibers** of the first plurality of **fibers**. Thus, the two pluralities of **fibers** have different inclination angles with respect to the longitudinal axis of the core. This is shown in FIG. 4 in the inclination angles of 20.degree. and 4.degree..

Detailed Description Text - DETX (31):
Preferably the **fibers** of the first plurality of **fibers** 60 have an

inclination angle with the longitudinal axis of the core of from 10.degree. to 40.degree. and the **fibers** of the second plurality of **fibers** 62 have an inclination angle with the longitudinal axis of the core of between 0.degree. and the inclination angle of the **fibers** of the first plurality of **fibers**. In a further preferred embodiment the **fibers** of the first plurality of **fibers** 60 have an inclination angle of from 10.degree. to 25.degree., especially 10.degree. to 20.degree., and the **fibers** of the second plurality of **fibers** 62 have an inclination angle of from 0.degree. to 7.degree., preferably 0.degree. to 4.degree., more preferably 2.degree. to 4.degree.. In an especially preferred embodiment, the pluralities of **fibers** have an inclination angle of 12.degree. and 4.degree., respectively.

Detailed Description Text - DETX (32):

The **hollow fiber** filament filling of the chamber may be achieved by arranging continuous strips of layers of **fiber** filaments around the core with the proviso that the axial width of said strips is longer than the axial distance between the sealings. Thus, continuous strips of layers of **fiber** filaments are formed and then these strips are in a second step arranged around the core, e.g. by spirally winding the continuous strip around the core. Since the axial width of the strips is longer than the axial distance between the sealings, the continuous strip need not be **wound** helically around the core which would involve passing the feed of the continuous strips along the longitudinal axis of the core. Thus, the arrangement of the continuous strips of layers of **fiber** filaments is much simpler in comparison to the yarn spool-like winding of the **fibers** according to the state of the art.

Detailed Description Text - DETX (33):

According to a preferred embodiment of the present invention two continuous strips of layers of **fiber** filaments are arranged around the core, wherein the strips have two parallel edges between which at least one layer of parallel spaced **fiber** filaments extends being inclined with respect to the parallel edges, wherein one strip contains the first plurality of parallel **fibers** with the first inclination angle and the second strip contains the second plurality of parallel **fibers** having the second inclination angle. The strips may have single layers of the **fiber** filaments and the two strips may be arranged around the core in a manner that contiguous layers of the core in radial directions have different inclination angles. This is indicated in FIG. 4.

Detailed Description Text - DETX (34):

The **hollow fiber** filament filling of the chamber may as well be achieved by successive layers of short single layer woven mats of the **fiber** filaments.

Detailed Description Text - DETX (35):
In these embodiments strips of mats of single layers of **fiber** filaments are prepared by first arranging a layer of long parallel **fibers** substantially equally spaced from each other which are then fixed in their position by a connecting element, preferably a cross thread which is a flexible small diameter monofilament. The thread must be sufficiently flexible to be easily bent around the **hollow fibers**. Furthermore, it must have sufficient tensile strength and tension to fix the filaments in their position, like in known tissues of clothes. This monofilament allows a regular **spacing** between the short single **fiber** filaments.

Detailed Description Text - DETX (36):
The essentially parallel **fibers** in each of the strips are spaced from each other by preferably 0.8 to 1.2 **fiber** diameters. The connecting element, preferably the thin filament-like connector or cross-thread is arranged transversely in all **fibers** of the strip in said strips or parallel to the upper and lower edges thereof.

Detailed Description Text - DETX (37):
In the embodiment of the present invention depicted in FIGS. 2 and 3 a known **hollow fiber** filament filling may be applied in which the **hollow fiber** filaments 44 extend inside the chamber 28' between the first cap 36 and the second cap 38. The circumferential angle difference of the **fiber** filaments between the sealings 46, 48 is not restricted and the directional sense of the **fibers** is not restricted either. However, a partitioning wall 70 described below has to be provided in this embodiment.

Detailed Description Text - DETX (38):
The **hollow fiber** filaments may be cross **wound** around the core as it is known from the prior art. This results in a first plurality of **fibers being wound** in one sense around the core, having one inclination angle, a second plurality of **fibers being wound** around the core in the opposite sense, having the opposite inclination angle. The circumferential angle differences are the same for both pluralities of **fibers** and this difference exceeds 360.degree..

Detailed Description Text - DETX (39):
Preferably the **hollow fiber** filaments have the arrangement described above for the first embodiment.

Detailed Description Text - DETX (40):
The **hollow fibers** are sealed in the space between the core wall and the outer wall at the top and the bottom thereof the ends of the filaments being

open so that a gas can flow through the **fiber** filaments. Preferably, the **fibers** are sealed with a polymeric resin which has the same thermal expansion coefficient as the **hollow fibers** and the housing. Useful resins are polyurethane resins, wherein epoxy resins are preferred. The resin sealing of the filaments is such that a chamber is formed between the core wall, the outer wall and the resin sealings in which chamber blood can flow but not penetrate the sealings. In the preferred embodiment the sealings are arranged in such a way that between the caps and the sealings a header space is left for the introduction or removal of the free oxygen containing gas. Furthermore, the sealings are arranged in such a way that the blood inlets and blood outlets are arranged in the walls inside the chamber formed by the core wall, the outer wall and the sealings.

Detailed Description Text - DETX (43):

The partitioning wall 70 may be provided in each of the embodiments of the present invention, i.e. in connection with a **hollow fiber** filament arrangement in which the circumferential angle difference for the **fibers** between the sealings of the chamber is between 0.degree. and 180.degree., wherein the first plurality of the **fibers** and the second plurality of the **fibers** have the same directional sense but different circumferential angle differences, the length of the **fibers** of the first plurality of **fibers** being different from the length of the **fibers** of the second plurality of **fibers** or in an arrangement in which the **hollow fiber** filaments extend inside the chamber between the first cap and the second cap.

Detailed Description Text - DETX (44):

Preferably, the partitioning wall is combined with the first arrangement of **hollow fiber** filaments. Preferably at least one partitioning wall extends from one of the sealings of the chamber to a position spaced from the other sealing of the chamber.

Detailed Description Text - DETX (47):

Further partitioning walls being sealed in the bottom sealing or top sealing may be arranged inside the chamber to further enlarge the flow path of the blood and enhance the gas exchange rate. In connection with the partitioning wall the annular chamber may be filled with the **hollow fiber** filaments in an arrangement wherein the **fibers** of the first plurality of **fibers** have an inclination angle with the longitudinal axis of the core of less than 90.degree. and the **fibers** of the second plurality of **fibers** have an inclination angle with the longitudinal axis of the core of between 0.degree. and the inclination angle of the **fibers** of the first plurality of **fibers,** preferably 10.degree. to 25.degree. and 0.degree. to 7.degree.,

respectively.

Detailed Description Text - DETX (48):
Best results are obtained when the **fibers** are arranged in the latter manner, especially at angles of 4.degree. and 12.degree., respectively.

Detailed Description Text - DETX (50):
Optionally the blood inlet of the **hollow fiber** oxygenator according to the present invention may be provided with a heat exchanger for controlling the temperature of the incoming blood. According to the preferred embodiments depicted in FIGS. 1 to 3 the heat exchanger is located in the bottom of the oxygenator inside the core of the oxygenator and comprises a plurality of metal tubes 80 in which a heat exchanging fluid is circulated. The blood is passed along the outsides of the metal tubes 80 which are spaced from each other. The fluid used to control the temperature inside the heat exchanger is preferably water.

Detailed Description Text - DETX (52):
According to the present invention a method for oxygenating blood is provided, comprising passing a free oxygen containing gas through a plurality of **hollow fiber** filaments extending principally axially through an oxygenator chamber and passing blood through the oxygenator chamber, wherein the blood flows primarily axially through the chamber along the plurality of **fibers,** characterized in that the **fibers** are arranged in such a way that they cause integrally a **helical** flow of the blood around the axis of the chamber.

Detailed Description Text - DETX (53):
According to a second embodiment of the present invention a method for oxygenating blood is provided, comprising passing a free oxygen containing gas through a plurality of **hollow fiber** filaments extending principally axially through an oxygenator chamber and passing blood through the oxygenator chamber, wherein blood flows primarily axially through the chamber along the plurality of **fibers,** characterized in that the blood in the first section of said chamber flows essentially in the opposite direction as the flow of the free oxygen containing gas through the **fibers** in said first section and that the blood in a second section of said chamber flows essentially in the same direction as the flow of the free oxygen containing gas through the **fibers** in said second section.

Detailed Description Text - DETX (56):
The gas used in the **hollow fiber** oxygenator according to the present invention may be any gas containing free oxygen which is apt to transfer oxygen

through the semipermeable **hollow fibers** into the blood and to receive carbon dioxide from the blood. Preferably, the gas should have a free oxygen content of from 21 to 100 vol. %, preferably from 60 to 90 vol. %. The preferred gas is air, which has an oxygen content of 21%, preferably mixed with a second free oxygen containing gas, so that the preferred oxygen content of from 60 to 90 vol. % is obtained. The gas pressure difference applied at the gas inlet and gas outlet may be from 0 to 13.3 kPa, preferably from 0 to 4 kPa. This results in a gas flow of from 0.2 to 10 l/min. for a preferred embodiment of the oxygenator according to the present invention as depicted in FIGS. 1 to 3.

Detailed Description Text - DETX (57):
To be useful in a cardiopulmonary bloodstream circulation of a human body the blood flow through the oxygenator must be in the range of from 1 to 6 l/min. In the blood oxygenator according to the present invention the blood flow may be arranged from 0.2 to 6 l/min., preferably from 1 to 6 l/min. To effect this blood flow a pressure difference of from 8 to 27 kPa must be applied between the blood inlet and the blood outlet. With a blood flow of 6 l/min. the typical residence time of the blood inside the **hollow fiber** oxygenator according to the present invention is 1/6 min. The flow path of the blood along the **hollow fibers** is approximately 180 mm. Details of the blood flow path can be seen in FIG. S. Without being bound to any theory it is believed that the blood flows along the **hollow** filament **fibers** helically around the axis of the chamber. This ensures an effective contact of the blood with the outer surface of the **hollow fibers** resulting in an improved oxygen exchange.

Detailed Description Text - DETX (58):
In comparison to the known blood oxygenators the **hollow fiber** blood oxygenator according to the present invention exhibits a high gas exchange rate while having a small size of the chamber filled with **hollow** filament **fibers**. No channeling of blood is observed in the oxygenator according to the present invention nor are areas of blood stagnation observed. The pressure drop of the blood flowing through the oxygenator is low.

Detailed Description Text - DETX (59):
The following examples demonstrate the advantages of the **hollow fiber** oxygenator according to the present invention with regard to the preferred embodiments.

Detailed Description Text - DETX (61):
A **hollow fiber** blood oxygenator according to FIG. 1 was assembled by using 3.2 up to 3.6 m.sup.2 of the **hollow** filament **fibers** manufactured by AKZO ENKA

GROUP to fill the annular chamber between the core wall and the outer wall. One half of the filaments were arranged with an inclination angle of 4.degree. with respect to the longitudinal axis of the core and the other half of the **fibers** were arranged around the core with an inclination angle of 12.degree. with respect to the longitudinal axis of the core. This corresponds to circumferential angle difference of 8.degree. and 25.degree., respectively. Two strips of **fibers** each having one of the different inclination angles were arranged in the chamber. The blood oxygenator was used to treat the blood coming from a patient in an extracorporeal circulation having an initial oxygen content of 11 ml/dl and an initial carbon dioxide content of 55 ml/dl. The applied blood pressure difference was 26.6 kPa and the applied pressure difference for the air was 4 kPa. Thus, flow rates for the gas were 6 l/min. and 6 l/min. for the blood. The blood leaving the oxygenator had an oxygen content of 19.3 ml/dl and a carbon dioxide content of 50 ml/dl. Thus, the blood oxygenator according to the present invention showed a superior gas exchange rate. No stagnation or channeling of blood and no agglomeration of blood particles was observed.

Detailed Description Text - DETX (63):

A **hollow fiber** blood oxygenator was arranged according to FIGS. 2 and 3 by using **hollow** filament **fiber,** manufactured by the AKZO ENKA GROUP. The annular chamber was filled with the **fibers** by cross winding. Further experimental conditions were as follows:

Detailed Description Text - DETX (67):

A **hollow fiber** blood oxygenator was arranged according to FIGS. 2 and 3 by using **hollow** filament **fiber,** manufactured by the AKZO ENKA GROUP. The annular chamber was filled with the **fibers** by the same method as applied in example 1. Further experimental conditions were as follows:

Detailed Description Text - DETX (72):

A commercially available **hollow fiber** blood oxygenator (DIDECO 7003 ITALIAN COMPANY) was used in a comparative experiment. Experimental conditions were as follows:

Detailed Description Text - DETX (74):

The results from Examples 1, 2 and 3 and comparative Example 4 show that the specific arrangement of **hollow fiber** filaments inside the **hollow fiber** blood oxygenator according to the present invention results in an improvement of gas exchange rate, while preventing channeling or stagnation of blood.

Claims Text - CLTX (1):

1. A **hollow fiber** oxygenator, comprising:

Claims Text - CLTX (3):
a plurality of selectively permeable **hollow fibers** extending in the chamber, each **fiber** having an open gas inlet end and an open gas outlet end, the inlet and outlet ends of the **fibers** being respectively sealed from fluid communication with the chamber;

Claims Text - CLTX (4):
a gas inlet to the inlet ends of the **fibers**;

Claims Text - CLTX (5):
a gas outlet from the outlet ends of the **fibers,** wherein gas may flow within each **hollow fiber** from the inlet end to the outlet end thereof;

Claims Text - CLTX (7):
a blood outlet from the chamber, wherein blood may flow through the chamber from the blood inlet to the blood outlet and contact the exterior surfaces of the selectively permeable **fibers, the fibers** enabling gas transfer between the gas flowing within the **fibers** and the blood flowing in the chamber; and

Claims Text - CLTX (8):
a partition wall in the chamber dividing the chamber into at least two sections with **hollow fibers** extending in each section, the sections defining a blood flow path from the blood inlet to the blood outlet, wherein in at least one section the blood flow direction along the blood flow path is counter-current with respect to the gas flow within the **hollow fibers** in that section, and in at least one other section the blood flow direction along the blood flow path is co-current with respect to the gas flow within the **hollow fibers** in that section.

Claims Text - CLTX (16):
9. The oxygenator of claim 8, wherein the gas inlet is disposed at the second axial end of the chamber and the gas outlet is disposed at the first axial end so that gas flows axially within the **fibers** from the second end to the first end, counter-current to the blood flow path in the first section and co-current to the blood flow path in the second section.

Claims Text - CLTX (22):
15. The oxygenator of claim 1, wherein the plurality of selectively permeable **hollow fibers** comprises successive layers of **fibers,** each layer of **fibers** comprising a plurality of **fibers** aligned in parallel and connected

together to form a mat, the **fibers** in each layer being oriented to form an angle with the **fibers** in each adjacent layer.

Claims Text - CLTX (23):

16. The oxygenator of claim 14, wherein the chamber is annular and each **fiber** extends helically between a first axial end and a second axial end thereof with a circumferential angle difference of less than, or equal to 180.degree..

Claims Text - CLTX (24):

17. The oxygenator of claim 16, wherein the circumferential angle difference of each **fiber** is less than or equal to 90.degree..

Claims Text - CLTX (25):

18. The oxygenator of claim 14, wherein the **fibers** in adjacent layers are **wound** helically within the chamber in the same rotational sense.

Claims Text - CLTX (26):

19. The oxygenator of claim 14, wherein the **fibers** in adjacent layers have inclination angles within 40.degree. of each other.

Claims Text - CLTX (29):

22. The oxygenator of claim 21, wherein the gas inlet is disposed at the second end of the chamber and the gas outlet is disposed at the first end so that gas flows within the **fibers** from the second end to the first end, counter-current to the blood flow path in the first section and co-current to the blood flow path in the second section.

Claims Text - CLTX (32):

passing a free oxygen containing gas through a plurality of **hollow fibers** extending through an oxygenator chamber, wherein the chamber is formed between an outer housing wall and an inner housing core wall;

Claims Text - CLTX (33):

passing blood through a first section of the chamber into contact with **fibers** in that section; and

Claims Text - CLTX (34):

passing the blood which flowed through the first section of the chamber through a second section of the chamber into contact with **fibers** in that section, wherein blood flows co-current with respect to the flow of oxygen containing gas within the **fibers** in one of the sections and counter-current

with respect to the flow of oxygen containing gas within the **fibers** in the other of the sections.

Claims Text - CLTX (38):

flowing gas axially within the **fibers** from the second end to the first end so that blood flows counter-current to the gas flow in the first section and co-current to the gas flow in the second section.

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INVENTOR-INFORMATION:

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PRIMARY-EXAMINER: Spear, Jr.; Frank A.

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ABSTRACT:

A balanced pressure tubular molecular filtration (Reverse Osmosis or Ultra Filtration) system in which semipermeable **membranes** are cast on or inserted into internal passages of a semiporous tubular substrate, and may also be cast on or affixed to the external surface of said semiporous tubular substrate, said tubular substrate also having one or more low pressure passages for collecting permeate water passing through said semiporous **membranes**, said tubular substrate being installed in a pressure vessel and operated in such a way that its external surface and all of its internal **membrane** coated passages

are exposed to operating pressure, so that mechanical forces are in balance, thereby overcoming hoop stress and burst strength problems common to internal pressure tubular molecular filtration designs.

17 Claims, 35 Drawing figures

Exemplary Claim Number: 14

Number of Drawing Sheets: 23

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Abstract Text - ABTX (1):

A balanced pressure tubular molecular filtration (Reverse Osmosis or Ultra Filtration) system in which semipermeable **membranes** are cast on or inserted into internal passages of a semiporous tubular substrate, and may also be cast on or affixed to the external surface of said semiporous tubular substrate, said tubular substrate also having one or more low pressure passages for collecting permeate water passing through said semiporous **membranes,** said tubular substrate being installed in a pressure vessel and operated in such a way that its external surface and all of its internal **membrane** coated passages are exposed to operating pressure, so that mechanical forces are in balance, thereby overcoming hoop stress and burst strength problems common to internal pressure tubular molecular filtration designs.

Brief Summary Text - BSTX (7):

1. In the case of segregated industrial waste streams, metal finishing and paint wastes, this invention makes it possible to reconcentrate these segregated wastes in such a way that they may be returned to the industrial process stream, thereby recovering valuable **materials**. Examples of this type of application include the recovery of metal phosphates from corrosion proofing processes (e.g. Parkerizing) chromic acid, nickel sulfamate, nickel fluoborate, copper pyrophosphate, zinc chloride and similar substances from plating rinse solutions, (R-18, C-9, C-15, C-17, C-18, C-19) and the recovery of latex, emulsion and electro-deposited paint residues from paint rinse and spray booth waters. (C-9, C-15, C-17 & C-18)

Brief Summary Text - BSTX (25):

This type of separation is accomplished by use of a semi-permeable **membrane**. In all practical methods for employing said **membrane,** the fluid to be treated is pressurized to a pressure substantially above the osmotic pressure of the

feed solution and passed across a substantial area of said **membrane**. During its transport across said **membrane,** water molecules preferentially pass through the **membrane,** with a small, limited amount of the dissolved substances also passing through.

Brief Summary Text - BSTX (26):

The amount of dissolved substances passing through said **membrane** is dependent upon numerous factors including (1) the nature of the **membrane** and its pretreatment, (2) the pressure and temperature, (3) pH, (4) the size and charge of the ions or molecules in solution and (5) the turbulence of the solution adjacent to the **membrane**. A large amount of specific data on the preferential passage or rejection of certain ionic or molecular species is known to those skilled in the art. (R-1, R-2, R-3)

Brief Summary Text - BSTX (28):

The limit of concentration of the final concentrate is dependent upon numerous factors, the most important of which relate to the maximum achievable concentration of the substances in solution, (saturation concentration) and the nature of solids once formed. However, in most commercial RO devices, the practical limit is considerably less than the saturation level, due to the fact that a preferential increase in the concentration of dissolved solids occurs at the **membrane** surface. This preferential concentration increase is often referred to as "Concentration Polarization". It results from the fact that water from the stagnant boundary layer passes though the **membrane,** increasing the concentration of solids in the residual liquid. Concentration Polarization is worst under conditions of laminar flow. It can be minimized by increasing the linear velocity or turbulence in the immediate vicinity of the **membrane** surface. It has been found that, at linear velocities of 0.38 M/sec or above, or at Reynold's numbers of 5,000 or more, the thickness of the stagnant boundary layer in contact with the **membrane** substantially decreases, thereby providing a major reduction in concentration polarization. For particularly intractible solutions, further improvement can be achieved by increasing the linear velocity to 1.5 M/sec or above or the Reynold's number to 20,000 or more. By such a reduction of boundary layer, solutions can be enriched to a final concentration closely approaching the saturation level of the least stable substances in solution, while, at the same time, minimizing **membrane** fouling, scaling and similar deleterious phenomena, with attendant loss of productivity and potential **membrane** compaction, (which results in permanent loss of productivity or total destruction of the **membrane.**) (R-1, R-2, R-3, R-4, R-5, R-6, R-7, R-8, R-9, R-10, R-11, R-12, R-14, R-15)

Brief Summary Text - BSTX (29):

The most commonly used RO **membranes** are manufactured from selected cellulose acetate resins. Other **membranes** include ethyl cellulose, polysulfone and composite **membranes** with, for example, ethyl cellulose overlying polysulfone.

Brief Summary Text - BSTX (30):
In the classical method for the fabrication of cellulose acetate **membranes,** a solution of the resin in one or more water soluble organic solvents is spread on a flat surface, such as a glass plate, and a doctor blade is drawn over the surface, thereby producing a layer of resin solution with uniform thickness. After several minutes of evaporation in the air, the plate is then lowered into ice water and left there until the resin gels and the water soluble organic solvents are leached from the **membrane**.

Brief Summary Text - BSTX (31):
As produced, these **membranes** have a very low tendency to reject substances in solution. To achieve increased rejection, the **membrane** is next placed in a bath of hot water for a prescribed period of time. Considerable literature is available on the temperature-time relationship and its effect upon the solute rejection characteristics of the heat treated **membrane**. (R-1, R-2, R-3, R-16) Casting techniques are also taught by Loeb (PJ-1, PA-1, 2, 3, 4 & 5), Mahon (JP-2) and Merten (JP-3).

Brief Summary Text - BSTX (32):
It is known that any flexing, bending or embossing of the **membrane** after casting, causes it to lose productivity or "flux", normally expressed as gallons per square foot per day, or tons (M.sup.3) per square meter per day. In his early work, Dr. Sidney Loeb (PA-1) discovered that, if he mounted his cellulose acetate **membranes** over high quality laboratory filter paper in his test holder, they would, nonetheless, lose flux due to embossment over the **fibers** in the paper; if, on the other hand, he mounted them over smooth Millipose Type HA filter **membranes,** their productivity was preserved. Therefore, it is beneficial to cast **membranes** directly on a rigid substrate, and to employ them without removal therefrom. It is also important to protect them from stretching due to the expansion of the surface on which they are mounted. (R-2)

Brief Summary Text - BSTX (37):
2. **Hollow Fiber,** as taught by Mahon (PJ-10) and Geory (PJ-11) and practiced by Du Pont. (C-2) (R-19, R-20)

Brief Summary Text - BSTX (38):
3. Spiral Module devices in which flat **membranes,** with the required

separators and spacers, are rolled into a cylindrical form, as taught by Merten (PJ-12, and 13, PA-6), Michaels (PJ-14), Westmoreland (PA-7), Bray (PA-8 and PJ-15) and Shirokawa (PJ-16), and as practiced by Universal Oil Products, Eastman Chemical and Envirogenycs Div. of Aerojet General Corp. (R-3, R-20, R-21) (C-1)

Brief Summary Text - BSTX (42):
Regarding No. 1, plate and frame equipment is limited in size due to the fact that the high operating pressures over even moderate cross sections, require extremely large bolts and tensioning members. It is also difficult to control external leakage. The **membrane** is, however, maintained in its original flat condition, though the support medium often causes embossing.

Brief Summary Text - BSTX (43):
In radioactive applications, flat sheets of **membrane** may be disposed of with ease. However, the small treating capacity of these devices eliminates them from consideration for the treatment of most nuclear facility wastes.

Brief Summary Text - BSTX (44):
Regarding No. 2, in the **hollow fiber** technique, minute capillaries of a semipermeable substance are mounted in a **fiber** wound pressure vessel, with the open ends of the capillaries penetrating through a header of epoxy or other encapsulating resin. When the solution is pumped through the pressure vessel, portions of the fluid penetrate the walls of the capillaries and pass down the internal passages to the permeate chamber. With a reasonable flow rate through the capillaries, a large back pressure develops. This back pressure may be as much as 200 psi (13.3 kg/cm.sup.2) at the midpoints of the **fibers**. Inasmuch as the maximum working pressure for the glass **fiber** pressure vessels used in **hollow fiber** devices is 600 psi (40 kg/cm.sup.2), this phenomenon results in a 33% loss in working pressure at these points, or a net working pressure of only 400 psi (26.7 kg/cm.sup.2). This phenomenon is known as "parisitic pressure loss". Since the osmotic pressure of many solutions exceeds 400 psi (26.7 kg/cm.sup.2), the applications for this technique are reduced. In addition, the flow of feed solution through the pressure vessel is rather slow and largely laminar. As a result, these devices are very sensitive to fouling by suspended solids and by scale forming substances. Feed solutions must be extensively prefiltered, and scale forming minerals (calcium, magnesium, iron) removed prior to treating with **hollow fiber** RO devices. In potable water service, broken **fibers** can permit microorganisms to enter the water supply.

Brief Summary Text - BSTX (45):
Due to its sensitivity to scale forming substances (calcium and magnesium),

and their limited pressure capability, **hollow fiber** devices are not suited to single pass desalination of sea water. They may, however, be employed as a second stage, following some other RO device.

Brief Summary Text - BSTX (47):
With respect to the problem of treating radioactive wastes, the **hollow fiber** devices suffer from the fact that the glass **fiber** reinforcement in the pressure vessels yields a high inorganic ash, thereby increasing the volume of waste which must be disposed of.

Brief Summary Text - BSTX (48):
Regarding No. 3, the spiral module technique employs **membranes** which are cast as flat sheets but are subsequently rolled, causing disruption of some of the **membrane** structure. Also, in service they become embossed upon the supporting layers of fabrics and screen, further reducing their desirable characteristics. There are also stagnation zones between the leaves of **membranes,** in which concentration polarization occurs. Further, suspended solids tend to build up on **membrane** surfaces, especially on the leading edge of the leaves of the spirals. In order to minimize the effects of suspended and dissolved solids, frequent reverse flow cleaning cycles are required. Costly valving is required in order to provide the reverse flow cleaning capability.

Brief Summary Text - BSTX (51):
With respect to the problem of treating radioactive wastes, the spiral module devices suffer from the fact that they contain metalic screens, spacers and other parts which add to the bulk of the final ash. Glass **fiber** fabrics, employed in some designs, further add to the ash which must be disposed of.

Brief Summary Text - BSTX (53):
Regarding No. 4, in internal pressure tubular RO devices a **membrane** is cast on or inserted into the inner surface of a porous tube. The tubing is subjected to internal pressure, with resultant hoop stress, causing the **membrane** to be stretched, permanently degrading its performance. These tubes can also rupture, causing catastrophic failure of the entire RO system, an intolerable condition for potable water and sewage application. As practiced commercially, several of these tubes are installed in parallel, pressed tightly between two headers, so the finished assembly resembles a heat exchanger tube bundle. These headers are maintained in place against the high fluid pressure by installing a tension rod between them, transmitting an objectionable compressional load to the **membrane** tubes in the "at rest" condition. However, under operating pressure, the load balance changes, resulting in a stress change on the **membranes** and tubes. Those stress changes induce fatiguing of

the **membranes** and of the porous tubes. Further, there are high stress concentrations in the immediate area of the header, which affect the life of the tubes and the **membrane**. Pressures in most internal pressure designs are limited to 800 psi (53.3 kg/cm.sup.2).

Brief Summary Text - BSTX (56):

In order to minimize some of these deficiencies of internal pressure devices, Patterson-Candy has employed costly perforated stainless steel supports around their **membranes, which membranes** are inserted therein in the form of a "soda straw", with a **membrane** film on the inner surface thereof. Maximum pressures are limited to 1,200 psi (80 kg/cm.sup.2). This design also employs large amounts of costly stainless steel in its headers and end pieces, greatly escalating the manufacturing costs.

Brief Summary Text - BSTX (57):

As mentioned under **hollow fiber** and spiral module, above, large systems require complex and costly high pressure manifolding to establish the proper flow rates in the several stages of series-parallel systems.

Brief Summary Text - BSTX (58):

Regarding No. 5, in the external pressure tubular design the **membrane** is cast on the outer surface of an essentially incompressible tubular, porous, ceramic **cores**. The permeate passes through the external **membrane,** on through the porous substrate, and into the internal permeate duct.

Brief Summary Text - BSTX (59):

One, seven or nineteen of these **cores** are installed in a 1, 2, 21/2 or 4 inch pressure vessel, and the permeate is ducted out of one end of the vessel. In most cases, a plastic covered wire or spring is wound around the tubular **core** to increase the tubulence. Since the **core** is pressurized uniformly and does not yield to this external pressure, the **membrane** is not subjected to stresses, as in the case of internal pressure tubular designs. Operating pressures to 1,500 psi (100 kg/cm.sup.2) have been achieved in these systems.

Brief Summary Text - BSTX (60):

In external pressure tubular designs, a hydraulic imbalance is created by the fact that one end of the **core** is subjected to system pressure but the other end communicates with the atmosphere. (The **core** is connected to the system at only one end rather than two, as in internal pressure and spiral module designs.) This imbalance has the beneficial effect of holding the string of **cores** in tight contact one with the other, while at operating pressure, thereby improving seal efficiency and minimizing internal leakage. However, this force

does subject the **core** to a longitudinal compressional force. The thickness of the ceramic walls must be sufficient to withstand radial and axial compressional forces without breaking. When **cores** are fabricated with less rigid porous substrates, such as **sintered polyethylene,** this longitudinal compressional force causes axial compression and radial enlargement of the **cores,** creating objectional tensional forces in the **membrane** skin and, in some cases, even causing the **membrane** to separate from the surface of the tube. It would be highly desirable to be able to employ these less rigid substrates, since the ceramic **cores** are fragile and require considerable care to prevent damage during handling and shipping. In some cases, the ceramic **cores** break in service, permitting large volumes of concentrate to contaminate the permeate.

Brief Summary Text - BSTX (61):
External pressure tubular RO devices can accept high inlet pressures and have a much lower sensitivity to hardness minerals than **hollow fiber** or spiral module devices, permitting single pass desalination of sea water. However, the possibility of broken **cores** or separated seals greatly limits the use of external pressure tubular devices in potable water supplies and makes them unsuitable for use in sewage systems.

Brief Summary Text - BSTX (62):
The external pressure design permits operation at very high turbulence and high linear flow rates. While the above mentioned longitudinal compressional force tends to maintain a proper seal between individual **cores** in a series string, this beneficial force is occasionally overcome by the high viscous drag experienced when operating at high linear flow rates. As presently manufactured, these viscous forces oppose the longitudinal compressional forces in one half of the pressure vessels. Recently, in several cases, these viscous forces have caused the connectors between **cores** in a series string to open, permitting concentrate to enter the permeate duct.

Brief Summary Text - BSTX (63):
Also, during system start up, prior to establishing system pressure, the hydraulic imbalance is not yet established and viscous forces may occasionally separate **cores,** causing serious internal leakage.

Brief Summary Text - BSTX (64):
With respect to the problem of treating radioactive wastes, the ceramic **cores** cannot be ashed, and, therefore, result in a very high volume of solid waste, increasing the nuclear waste disposal problem. Further, conventional turbulators are made of plastic coated wire. The residual wire further complicates disposal problems.

Brief Summary Text - BSTX (65):

Practical considerations limit external pressure tubular devices to two commercial configurations, 7-**core** and 19-**core**. As a matter of fact, 19-**core** bundles present such severe assembly, installation and maintenance problems that their applications are very limited. However, assuming that, with care, they could be used, they cannot accept feed rates in excess of 250 tons per day. Systems with larger flow rates require complex and costly high pressure manifolding to permit series-parallel operations, so that each cell may operate within established hydraulic limits.

Brief Summary Text - BSTX (67):

I have invented a totally new RO design in which I have preserved the beneficial effects of internal and external pressure RO devices, while, at the same time, overcoming most of the deficiencies associated therewith. This new device is defined and described as the "balanced pressure tubular" design. It employs a tube or **core** composed of a porous substrate, containing internal, tubular, **membrane** coated surfaces. The external tubular surface may also be coated with **membrane,** though the external surface is more subject to damage; further, the external surface only makes a significant contribution to the total **membrane** area in the smaller **core** sizes.

Brief Summary Text - BSTX (68):

In order to understand the various phenomena with respect to my device, it is necessary to realize that it contains two separate, though related, force or pressure systems. One is a mechanical system consisting of a heterogeneous, porous solid. The other is a hydraulic system consisting of wter or an aqueous mixture of solutes in water. Under dynamic, operating conditions, aqueous media surround the tubular **core** and fill the internal tubular passages, plus the cavities within the heterogenous, porous solid.

Brief Summary Text - BSTX (71):

1. Tensile stress on **membrane** due to hoop stress on supporting tubing.

Brief Summary Text - BSTX (76):

6. Relatively low "packing density" (square meters of **membrane** per cubic meter of cell bank.)

Brief Summary Text - BSTX (82):

1. Brittle small diameter ceramic **cores** often break during shipping, handling, installation and, occasionally, in service.

Brief Summary Text - BSTX (83):
2. Large number of seals increases the chance of seal failue. [There are 133 separate **core** seals in a standard 7-**core,** 18.5 foot (5.64 meter) pressure vessel.]

Brief Summary Text - BSTX (84):
3. Standard design with 7 or 19 **cores** in parallel and six strings in series makes assembly nd installation difficult, requires 4 men to insert or remove a bundle of **cores**.

Brief Summary Text - BSTX (85):
4. Large longitudinal and radial compression forces increase required thickness of **core** substrate, increasing weight, with resultant increase in **material** and transportation costs.

Brief Summary Text - BSTX (86):
5. Hand wound turbulator wires or springs used on **cores** increase assembly costs.

Brief Summary Text - BSTX (87):
6. "Dead space" between **cores** reduces hydraulic efficiency.

Brief Summary Text - BSTX (89):
8. Relatively low "packing density" of **membrane**.

Brief Summary Text - BSTX (91):
10. Ceramic **cores** with uniformly circular cross sections are an absolute necessity or the **core** will not pass through the ring die. In cases of moderate "elipticity" of the **core,** a non-uniform layer of **membrane** results.

Brief Summary Text - BSTX (92):
11. Many small parts, connectors, turbulators and seals are required on **cores,** increasing complexity and chance of failure.

Drawing Description Text - DRTX (2):
FIG. 1. Balanced pressure **core** with one feed tube and one permeate duct, transverse cross sectional view.

Drawing Description Text - DRTX (6):
FIG. 5. Cylindrical balanced pressure **core** with two permeate ducts and one eliptical feed tube.

Drawing Description Text - DRTX (7):
FIG. 6. Eliptical balanced pressure **core** with two permeate ducts, one cylindrical feed tube.

Drawing Description Text - DRTX (8):
FIG. 7. Conventional 21/2" external pressure 7**-core,** Reverse Osmosis Device.

Drawing Description Text - DRTX (9):
FIG. 8. 7**-core,** 21/2" device using balanced pressure **cores** illustrated in FIGS. 1 and 2, transverse cross sectional view.

Drawing Description Text - DRTX (13):
FIG. 11. Device of FIG. 1, contoured to nest closely in 5**-core** device.

Drawing Description Text - DRTX (14):
FIG. 12. Device of FIG. 1, contoured to nest closely in 8**-core** device.

Drawing Description Text - DRTX (15):
FIG. 13. 5**-core** device with two feed tubes, **cores** contoured to nest closely.

Drawing Description Text - DRTX (16):
FIG. 14. Same as the device of FIG. 13, but 6**-core** design.

Drawing Description Text - DRTX (21):
FIG. 19. Longitudinal cross section of the device of FIG. 15, showing means of interconnecting **cores**.

Drawing Description Text - DRTX (23):
FIG. 21. The device of FIG. 15 with perforated metal liner and pipe threads for interconnecting **cores**.

Drawing Description Text - DRTX (24):
FIG. 22. The device of FIG. 15 with a perforated metal liner, tubing fittings for interconnecting **cores,** a swivel joint to permit rotation and an impeller to augment the rotational torque.

Drawing Description Text - DRTX (32):
FIG. 30. Composite **core** structure with m=0 for n=1, m=5 for n=2 and 3, and m=6 for n=4 through 8. Higher density substrate extending past row n=3.

Drawing Description Text - DRTX (35):
FIG. 33. The device of FIG. 21 with external "O" ring gasket to prevent flow around outer surface of **core**.

Detailed Description Text - DETX (2):
My invention is described by a series of drawings. FIG. 1 shows a cross section and FIG. 2 an isometric rendering of the simplest embodiment of my invention. **Core** 1 is a porous tube with two tubular internal passages. Item 2 is a relatively large tube for internal passage of feed solution, here shown as a cylindrical surface, though there is no intrinsic limitation dictating that it be such. Similarly, item 3 is a relatively small tube for internal passage of permeate, also shown as cylindrical, but not herein limited to said contour. The outer surface of **core** 1 is also shown as cylindrical, but again is not intrinsically limited thereto. Item 4 is a **membrane** on the inner surface, 2, where it is either cast in place or inserted after fabrication. Item 5 is an optional **membrane,** cast on or attached to the outer surface of **core** 1.

Detailed Description Text - DETX (3):
Passage 3 is the permeate duct for this RO **core**. In service, it communicates with the outside of the machine and is maintained at, or close to, atmospheric pressure. The tube itself is installed in a pressure vessel, item 7, and the **membrane** coated inner surface and the outer surface of the **core** 1 are exposed to balanced system pressure. The **membrane** surfaces resist the intrusion of ions and molecules of dissolved solids (solutes), but permit water molecules to pass with relative ease. Once the water molecules have passed through the **membrane** skin, they proceed into the relatively low density substrate, item 6. This substrate may be composed of ceramic **materials,** **sintered** glass, **sintered** metal, **sintered** or foamed plastics such as **polyethylene,** polyvinylidene fluoride, polyvinyl chloride, acetal, polystyrene or polyurethane, granulated or foamed rubber, fused, consolidated, resin treated or otherwise fixed sand, silica, feldspar, clay, diatomaceous earth or other inorganic mineral or fossil substance, treated wood, wood **fiber** or wood powder, consolidated coal, asphaltite, gilsonite or other bitumen powder, or any one of a number of other porous solid substances. (The use of plastic, coal, asphaltite, gilsonite or other bitumen, rubber, wood based or other organic substrates is particularly beneficial for use in treating radioactive wastes, since they may be converted to an ash or chemically decomposed to minimize the volume of radioactive waste.)

Detailed Description Text - DETX (4):
The water molecules can pass through the porous substrate to tube 3, which is the permeate duct. The highest flux through **membranes** seldom exceed 0.014

ml/cm.sup.2 /minute. Consequently, the internal flow rates are very low. Many available porous substrates can accept these flows without creating objectionable internal parisitic pressure drops. (This matter is further analyzed in a subsequent section.)

Detailed Description Text - DETX (5):
Item 8 shows the end of the **core,** which may be sealed by fusing, glazing, encapsulating or other technique. In the absence of **membrane** 5, the outer surface of **core** 1 would also be sealed against fluid intrusion, or it may be surrounded with a thin plastic or metal shell, as shown in a subsequent drawing.

Detailed Description Text - DETX (6):
Item 8 is a connector for connecting the **core** to the outside of the machine, or for coupling the **core to another core** of the same type in a series string. FIG. 3 shows the opposite end of the same **core,** on which there is installed a similar, but mating connector, item 10. If this **core** was to be used alone, or was to be the last in a string of **cores** in series, a blind plug, such as item 12, and seal 13 would be inserted in connector 10. A turbulator, item 11, surrounds **core** 1 as an optional accessory.

Detailed Description Text - DETX (7):
This design has the considerable advantage that **membrane** coated surfaces, 4 and 5, and supporting structures, 6, are exposed to balanced pressures. The **membrane** coated internal tubular surface, 2, is not exposed to hoop stress, as in the conventional internal pressure design. The outer surface is not exposed to high compressional forces. The granules of heterogenous substrate below the **membranes** carry these forces. There are radial compressional forces in the area of the permeate duct, but the large amount of solid substrate in that zone provides adequate support against them. The bulk of the end faces, 8, are exposed to balanced axial compressional forces. A small area near the permeate duct, 3, physically carries the hydraulic load imposed by the fact that one end, 12, is exposed to system pressure while the other communicates with the atmosphere.

Detailed Description Text - DETX (9):
FIG. 4 shows a further embodiment of my invention, in which a perforated stainless steel liner, item 20, is inserted into the permeate duct, 3. This extra reinforcement is particularly suitable where high operating pressures or thin wall sections are to be employed. It is also an important component of the configuration of my device recommended for producing potable water and for treating sewage wastes. This internal liner 20 may be extended beyond the ends

of the porous tube, 1, facilitating the inter-connection of a series string of **cores,** and the delivery of the permeate. For potable water, food product and sewage applications, suitable tubing connectors, pipe couplers or sanitary fittings may be employed to provide highly reliable inter**-core** connections, as further described below.

Detailed Description Text - DETX (10):
FIGS. 5 and 6 show cross sections of similar tubes in which two permeate ducts are employed and in which either the outer or inner profile is an elipse or other contour which permits the use of two permeate ducts, and maximizes the amount of **membrane** surface.

Detailed Description Text - DETX (11):
FIG. 7 represents a standard 7**-core** external pressure tubular RO design and FIG. 8 shows how a similar pressure vessel could accommodate seven balanced pressure **cores,** designed in accordance with the principles described above. In this modification, FIG. 8, the packing density of **membrane** has been substantially increased by providing **membrane** on both inner, 2, and outer surfaces of the porous **cores**. This design yields substantially increased permeate when compared to the conventional design, FIG. 7.

Detailed Description Text - DETX (12):
FIGS. 9, 10 and 10A show ways in which the strength of the boss and the diameter of the permeate duct may be increased. However, for casting efficiency it has been found to be preferable to maintain a circular cross section for the **membrane** coated inner surface or surfaces of a **core**.

Detailed Description Text - DETX (13):
FIGS. 11 and 12 show designs intended to be used in the same pressure vessels as those used for a standard external pressure, 7**-core** RO system. Morphologically, these **cores** are the same as shown in FIGS. 1 and 2. However, the outer surfaces have been contoured so that the individual **cores** nest together, eliminating the "dead space" shown in the standard external pressure design, FIG. 7, item 21. In these designs, FIGS. 11 and 12, turbulators (FIG. 2, item 11), must be installed on at least half of the **cores** to keep the adjacent surfaces separated and to permit fluid flow. The design shown in FIG. 12 provides 2.5 times as much **membrane** surface as the standard 21/2 inch, 7**-core,** external pressure tubular design, FIG. 7, for a 150% increase in **membrane** area. This increased **membrane** area provides a comparable increase in the amount of permeate produced by a given section of pressure vessel, thereby substantially reducing the number of costly pressure vessels, manifolds, etc. in a cell bank. Progressing from the 5**-core** design, FIG. 11, to the 8**-core**

design, FIG. 12, the strength of the permeate duct may be progressively increased.

Detailed Description Text - DETX (14):

FIGS. 13 and 14 expand further upon the concept introduced in FIGS. 11 and 12. In these designs, two internal tubular surfaces, 2, are coated with **membrane** and a third, 3, is employed as a permeate duct. In FIG. 14, the **membrane** surface is 2.6 times that of the standard external pressure, 21/2 inch design, FIG. 7, for a 160% increase of **membrane** area.

Detailed Description Text - DETX (15):

For ease of installation, maintenance and service, it is beneficial to reduce the number of permeate connections. Therefore, in FIGS. 15 and 16 I show one of the preferred embodiments of this invention. The central tube, 32, is the permeate duct, and all other internal tubular surfaces, 31, are coated with **membrane,** 4. The external surface may also be coated with the optional **membrane** 5. This design offers numerous advantages over my other balanced pressure tubular designs. Except for the internal tubular passages, item numbers on the figures have the same meanings as on previous figures. The principle difference is in the use of many cylindrical, **membrane**-coated, internal tubular surfaces, 31; one cylindrical external surface with optional **membrane,** 5; and one central, uncoated permeate duct, 32, equipped with connectors.

Detailed Description Text - DETX (19):

FIG. 19 is a cross section of two **cores** designed in accordance with FIG. 15, showing a means for interconnecting individual **cores**.

Detailed Description Text - DETX (20):

FIG. 20 shows an assembly of pressure vessels containing **cores** similar to those illustrated in FIGS. 15 through 19. The internal passages are not shown. In addition to the other standard designations, 41 is the permeate collector, 42 is the permeate portion of the header casting, 43 is the feed return portion of the header casting, 44 is a pipe coupler, 45 is a retainer flange placed at the permeate end of the pressure vessel, 46 is a gasket for pipe coupler 44, and 47 is a collar for pipe coupler 44. While I have found this configuration to be an improvement over designs in which one end of the machine has only type 42 headers and the other end only type 43 headers, my **core** design can be employed in either way, provided that a non-slip connector design is employed, e.g. bayonette or threaded connector, pipe or tubing fitting.

Detailed Description Text - DETX (23):

1. There is no problem of **membrane** being put under tension due to hoop stress, since the internal and optional external **membrane** coated surfaces of the **core** are in static mechanical balance.

Detailed Description Text - DETX (28):

7. Catastrophic failures of tubing are eliminated. In the case of minor **membrane** defects, **membranes** supported on a semi-porous substrate undergo a "self-healing" phenomenon when minor **membrane** defects occur. Suspended solids in feed solutions usually plug the passages in the substrate, eliminating such leakage paths. When required, this process can be accellerated by introducing a latex or a vegetable gum into the feed. If a defect does not yield to this treatment quickly enough, a single segment of a series string of **cores** may be replaced in the field. Since the pressure carrying vessel, item 5, is a piece of conventional pipe, it is unaffected by such a defect. Only the **core** requires repair or replacement.

Detailed Description Text - DETX (30):

1. The **cores** shown in FIGS. 15 through 19, even if fabricated with ceramics, have a much larger overall cross section (diameter to length ratio) than conventional external pressurized **cores**, increasing strength and minimizing the problems of breakage. Further, a much broader range of engineering **materials** may be employed in their construction. For example, **sintered** plastics, such as **sintered polyethylene**, are not fragile and can be employed in my invention.

Detailed Description Text - DETX (31):

2. Instead of seven pairs of couplers per joint (0.91 meters), as in the 21/2 inch 7-**core** external pressure design, in my invention there is only one pair. In addition, 2 meter **cores** may be made, whereas conventional external pressure designs are limited to 0.91 meters, due to the brittle nature of the small diameter ceramic **cores**. This factor permits a further 55% reduction in the number of joints.

Detailed Description Text - DETX (32):

3. **Cores** may be individually connected as they are inserted by a lone operator, thereby eliminating the need for a four man team.

Detailed Description Text - DETX (34):

5. Only one turbulator is required per joint, instead of the conventional 7 or 19, as in the 21/2 inch or 4 inch external pressure tubular designs. In the absence of the optional external **membrane**, it can be totally eliminated.

Detailed Description Text - DETX (35):

6. The diameter of the internal passages and the annular clearance between the **core** and the pressure vessel can be controlled and designed to provide optimum hydraulic efficiency and flow distribution (internal and external), thereby eliminating the problem of dead spaces between **cores** and the poor flow distribution of conventional designs. When the external **membrane,** 5, is omitted, a close fitting **core** will minimize external flow. Or, a single "O" ring or similar seal or gasket may be employed to prevent external flow without sacrificing the balanced pressure concept.

Detailed Description Text - DETX (37):

8. Higher packing densities are achieved, providing 147% more **membrane** than achieved with conventional 21/2 inch 7**-core** external pressure tubular designs.

Detailed Description Text - DETX (38):

9. Since individual joints can be connected at the machine as they are inserted, the clear working space can be limited to the length of one **core** segment; for example, one meter will suffice for 1 meter **cores,** instead of the usual 6 meters required for 7**-core** external pressure tubular designs.

Detailed Description Text - DETX (39):

10. **Sintered** or otherwise consolidated **cores** are more nearly true to the circular cross section of their mandrel than are ceramics. (Considerable effort must be expended in order to prevent "slumping" or flattening of ceramics during firing.) Circular cross sections are essential for external pressure tubular **membrane** casting efficiency.

Detailed Description Text - DETX (40):

11. Only one set of connectors is required per joint, instead of the usual 7 or 19. Further, the connectors can be molded directly into plastic substrates, as shown in FIG. 19, improving the seal efficiency and limiting the required elastomeric seals to one per joint, instead of the usual three. In the case of 19 **core** designs, this savings permits the elimination of 38 elastomeric seals per joint. Then, as mentioned in item 2, above, the joints may be made 2 meters in length instead of 0.91 meters, for the equivalent savings of 84 seals per segment.

Detailed Description Text - DETX (42):

13. Seal failures due to viscous drag are eliminated by use of the castings described in item 12, above, and shown in FIG. 20. **Cores** may be installed in such a way that the forces of viscous drag are always in the same direction as the longitudinal compressional forces, rather than opposing them in half of the

cells, thereby improving connector reliability.

Detailed Description Text - DETX (45):

2. The end faces of individual joints of **cores** need not be equipped with seals, since they may be fused, encapsulated or otherwise rendered impervious without the use of additional elastomeric seals. This innovation is particularly beneficial for preventing impingement from the suspended solids present in some feed solutions.

Detailed Description Text - DETX (46):

3. **Cores** as shown in FIGS. 15, 16, and 19 may be used to retrofit external pressure tubular 7**-core** systems, thereby achieving increased performance at the same operating pressure or the same product water flow at much lower pressures, and substantially reducing operating costs. Similarly, the 4 inch design shown in FIG. 18 can be used to retrofit external pressure 19**-core** systems.

Detailed Description Text - DETX (47):

4. A further unexpected operational advantage has been realized due to the space provided between **cores** in series. In internal and external pressure tubular designs, high concentrations of solutes and stagnant boundary layers develop in the immediate vicinity of the **membrane** surface, and spread down stream as the feed solution progresses through or around the tubes. However, in my design the fluid passes into the 1 to 15 cm. space between joints, where the feed from the internal tubular passages and the optional external annular passage are thoroughly mixed under turbulent conditions, prior to entering the next segment of balanced pressure tubular RO **core**.

Detailed Description Text - DETX (48):

5. Because of the balanced pressure design, large wall sections between the outer tubular surface and internal tubes are not required, nor are large separations required between adjacent internal tubular surfaces. These characteristics facilitate maximizing of packing densities. If the walls are sufficiently strong to prevent rupture during manufacturing, shipping and installation, and if they permit passage of the permeate, they will not fail in normal service. The coefficient of fluid resistance of many available porous substrates is much higher than that of **membranes,** resulting in relatively low internal flow rates. Further, the geometric considerations relating to tubing layouts provide adequate cross sections for the transmission of permeate from the **membrane** surfaces to the permeate duct, so that parasitic losses can be controlled. This matter is discussed extensively, below.

Detailed Description Text - DETX (49):

6. When **core materials** are selected from one of the classes of porous organic substrates (e.g. plastic, bitumen, etc.), and when the turbulators, connectors and seals are also composed of organic substances, the resultant device is particularly suitable for use in nuclear applications. It may be decomposed by thermal or chemical means, yielding the smallest possible volume of solid waste.

Detailed Description Text - DETX (50):
7. Due to the broad latitude in the diameter of pressure vessels and **cores,** complex, high pressure, series--parallel manifolding is not required, as further delineated below.

Detailed Description Text - DETX (51):
FIG. 21 shows another configuration based upon the design shown in FIG. 4, in which a perforated liner, 20, is employed in the porous **core**. In this case, the perforated liner extends beyond the end of **core** (perforations only within the **core**) and terminates in a pipe coupler, 50, facilitating interconnecting of **cores**. The threaded end may then couple directly into the retainer flange, 45, without the need for an unreliable permeate collector, item 41, FIG. 20. The terminal **core** is then plugged with a conventional pipe cap, 51.

Detailed Description Text - DETX (53):
This design has been found to be one of the most adaptable, since it greatly simplifies installation of **membranes,** minimizes leakage, and yields the highest reliability in potable water and sewer applications. The high pressure capability, combined with high reliability, permit this design to be used in single pass desalination of sea water. The optional swivel joint permits the string of **cores** to rotate slightly, especially on start up, driven by the torque created by the turbulator 11. This innovation minimizes the propensity for fouling and suspended solid (SS) buildup on the under side of the optional external **membrane**. For larger sizes of **cores,** the relatively smaller volume of feed solution passing through the annulus is not sufficient to cause rotation of the string of **cores** on start up, necessitating the use of the optional impeller, item 67.

Detailed Description Text - DETX (55):
With the designs shown in FIGS. 21, 22 and 23, a rotation of the **cores** may be effected intermittently without the use of the swivel joint. During regular maintenance periods, the pipe couplings, 44, may be loosened and the retainer flange, 45, manually rotated 60.degree. to 90.degree., thereby rotating the entire string of **cores**.

Detailed Description Text - DETX (57):
With the designs shown in FIGS. 21, 22 and 23, the problem of seals and slip fittings being pulled apart due to viscous drag is totally eliminated. Accordingly, no special attention need be given to maintaining flow toward the permeate end of the pressure vessel. In the case in which a swivel joint is employed to cause **core** rotation, it is preferable to have flow away from the permeate end of the pressure vessel, the reverse of what is shown in FIG. 20.

Detailed Description Text - DETX (61):
With **hollow fiber,** spiral module and internal and external pressure tubular RO, economical considerations have dictated that pressure vessels and modules be limited to a maximum of two or three sizes. These limitations result from numerous factors, such as the use of highly specialized castings, various manufacturing tools and fixtures, geometric considerations, etc. However, with the elimination of these constraints, new opportunities for improved designs were created.

Detailed Description Text - DETX (64):
In order to illustrate some of the possible **core** designs, Table I shows the characteristics of many of the combinations and permutations

Detailed Description Text - DETX (65):
of **cores** which could be manufactured under this general principle. The pipe sizes shown range from 11/2" to 48". At the bottom of this table are shown the characteristics of one commercially available internal and one commercially available external pressure tubular design.

Detailed Description Text - DETX (67):
Table I shows that, as the diameters of the pressure vessels increase, the ratio of the internal to external **membrane** surface increases. The external surface varies as the first power of the O.D., whereas the internal area varies approximately as the square of the O.D. In addition, as the size increases, the possiblity of damaging the external **membrane** increases, and dimensional considerations make it very difficult to cast a good **membrane**. **Membranes** are normally only 75 to 150 microns thick. While, for short **cores,** dip casting has been used (R-22), superior **membranes** are achieved by use of "extrusion" through rigid ring dies. With these dies, **core** elipticity must be carefully controlled to 25 to 50 microns maximum. It is every difficult to fabricate large porous **cores** with this degree of precision in their outside surfaces.

Detailed Description Text - DETX (68):
However, due to handling problems, and since the external **membrane** provides

only a small portion of the total **membrane** on a large **core,** it is beneficial to omit the optional **membrane** (5) on the external surface of larger **cores**.

Detailed Description Text - DETX (69):
The right half of FIG. 27 shows a cross section of an 8" **core** in which there would be 210 internal tubular **membrane** coated surfaces and no outer **membrane** coated surface. For simplicity, the internal **membranes,** 4, have not been shown in this and subsequent figures. The outer surface may be sealed as in item 7, FIG. 1, or a thin metallic or plastic shell, 90, may surround the **core**.

Detailed Description Text - DETX (70):
Referring again to Table I, under the 8" entry I have shown one design with external **membrane** and eight different designs without external **membrane**. In the design with the external **membrane,** I have shown 216 internal tubular **membrane** coated surfaces, whereas the first of the designs without an external **membrane** has only 210 internal tubular surfaces. The reason for this difference is that, with increasing volume of permeate, it is necessary to increase the diameter of the permeate duct. In order to accommodate the larger duct, it was necessary to omit the inner row of tubular surfaces.

Detailed Description Text - DETX (71):
Another problem developed as the size of the **cores** increased. This problem resulted from the geometrical limitation on the clearance between tubes in the first row. As an hypothetical example, if the diameter of the tubes in this inner row were equal to their distance from the center line, they would be tangent to one another and no flow of permeate could pass from the outer rows to the permeate duct. For example, if the first row of tubes were to be located on a circle 1 centimeter from the central axis, and if the tubes were 1 cm in diameter, placed every 60.degree., they would touch, and there would be no space for porous substrate between them. On the other hand, if the centers of the tubes on the second row of said **core** were to be on a circle 2 centimeters in diameter, and one centimeter tubes were to be placed every 30.degree. around the circle, a small clearance would exist between tubes, as shown in FIG. 28. The center-to-center distance between these tubes is 4 sin 15.degree.=1.0353. Since the radius of the **cores** is only 0.5 centimeters, a clearance of 2(0.518-0.500)=0.036 would exist. Similarly, in the third row, 18 tubes would be placed 20.degree. apart and the distance between centers would be 6 sin 10.degree.=1.0419 cm. The clearance between adjacent one centimeter tubes would be 2(0.521-0.500)=0.042 cm. Therefore, it is seen that, for rows beyond the first row, there is a significantly larger clearance available for permeate to flow toward the permeate duct. This phenomenon is best seen in the difference between the arcs and the chords, as follows: ##EQU1## where A is the

length of the arc between centers of adjacent tubes,

Detailed Description Text - DETX (81):

One solution to this problem is to have the tubes in the first row slightly smaller than those in rows 2 and above. However, the flow rate in the smaller tube would be lower, resulting in poorer rejection. In marginal cases, it would result in preferential fouling of the **membranes** in the smaller tubes. I therefore prefer to have all tubes the same diameter. For Ultra Filtration, where the flux is particularly high, I have found that, even with the smaller sizes of **cores,** such as the 3", Schedule 5S, 36 tube design shown on Table I (entry 5), it is frequently beneficial to omit one of the tubes in the central row, reducing the total number of tubes to 35; the area of internal **membrane** is thereby decreased from 1.19 to 1.16 M.sup.2 /M and the total **membrane** decreased from 1.44 to 1.41 M.sup.2 /M, a loss of only 2%.

Detailed Description Text - DETX (82):

The simplest design is based upon six tubes in the first row and six more tubes in each subsequent row of a **core**. In order to show the effect of a larger or smaller increment, FIG. 29 is presented. In this figure, a 6" pipe is illustrated. The symbol "n" is again used to represent the row number, and "m", the number of tubes in each row. In the smallest circle shown, n=2; Row n=1 has been omitted. In section A, m=6. In sections C and D, m=7 and in rows E and F, m=5.

Detailed Description Text - DETX (83):

The diameter of the tubes in sections A, B and F is the same. In section F (where m=5), it is apparent that there is much lost space between tubes in the same row, resulting in a lower packing density than in section A. (There are some potential benefits from this increased space, especially in the case of Ultra Filtration, where flux rates are very high.) In Section E, in order to take advantage of the available space in row n=2, the diameter of the tubes in row n=2 have been increased. However, it was then necessary to increase the diameter of the circle n=3. This increase made it possible to further increase the diameter of tubes in row n=3. Accordingly, the diameter of the circle n=4 had to be increased, making possible a further increase in the diameter of the tubes in row n=4. Ultimately, the diameter of the tubes in row n=5 grew to 1.6 times the diameter of the standard tubes in sections A and F, and the circle n=6 was lost. Since, as previously noted, it is undesirable to have more than one size of tube in a **core,** the design shown in Section E would not be desirable for RO.

Detailed Description Text - DETX (86):

In section B is shown an alternate design in which, for rows n=2 and n=3, m=5. This concept is beneficial for very large **cores,** especially when there is limited porosity of the substrate. For rows n=4, 5 and 6, of section B, m=6.

Detailed Description Text - DETX (99):
I prefer to maintain R.sub.t between 0.5 and 2.0 cm and S between 0.1 and 0.6 cm, depending upon **core** size, substrate permeability and **membrane**

Detailed Description Text - DETX (102):
As will be shown below, unbalanced compressional forces are restricted to the space within the center line for the innermost circle of tubes. For **cores** up to 2", it is best to use the more rigid of the available porous substrates. However, for larger **cores,** it is possible to make use of a composite structure in which a substrate with lower compressional strength and greater flexibility (larger pore size, higher void volume and lower elastic modulus) is built up on a precast 2" or 3" **core**. For example, for nuclear applications, a 2" or 3" **sintered polyethylene core** can form the central portion of a 12" **core** in which the outer portion is composed of a semi rigid plastic foam. Such a **core** possesses superior characteristics for shipping, handling and installation. Similarly, for potable water applications, a 2" or 3" **sintered** silica **core** can support a similar plastic foam **core** of larger diameter. Such a design is illustrated in FIG. 30, in which, for the central section, m=5, and n=2 and 3. The more dense central substrate is shown as item 91. Or, a central section of substrate up to 3 cm in diameter, with no tubes except the permeate duct, can be used to carry a portion of the higher unbalanced force within the innermost circle of tubes. Such a central section is shown as item 92, FIG. 27. As previously noted, for larger sizes no tubes are used in the row n=1, so that it is only required that the central **core** be small enough so that it would not conflict with the tubes in the second row. The 3 cm dimension satisfies this requirement for the designs shown in FIG. 27. By use of this composite **core** design, the unbalanced internal mechanical forces are carried by the central substrates, which are best able to withstand them.

Detailed Description Text - DETX (103):
A decrease in manufacturing costs also results from the use of these composite **cores**. Tooling costs, fabricating costs and energy consumption are much lower for some of the softer or less dense **materials** employed in the outer portion of the larger sizes. **Core** weight, and the attendant handling difficulties, are also substantially reduced.

d Description Text - DETX (104):
G. 27, vectors "P" illustrate the way in which system pressure is

applied uniformly to the internal and external surfaces of **core** 1. The force on the internal surface, for a one centimeter length of **core,** may be expressed by the equation for hoop stress, as follows:

Detailed Description Text - DETX (113):
In order to evaluate the phenomena which occur within the static mechanical system, without the complications introduced by the hydraulic system, it is valuable to consider a hypothetical **core** in which all surfaces exposed to system pressure are sealed against fluid passage, i.e., a **core** without **membrane** and with no fluid flow within the porous substrate. Next, we assume that the permeate duct communicates with the atmosphere, so that the pressures within the permeate duct and in the voids within the porous substrate, are Zero (gauge).

Detailed Description Text - DETX (114):
Under such circumstances, the compressional loads are seen to be in balance in all parts of the **core,** with one exception. Within the center line circle on which the centers of the innermost row of tubes is located, a compressional force imbalance exists. For example, referring to the right side of FIG. 27, a mechanical pressure imbalance exists in the substrate located within the innermost circle of tubes. With substrates possessing high elastic moduli, low void volumes and small particle sizes, this mechanical load is dissipated within the first few layers of the substrate granules on the convoluted profile, within the center line circle (n=2). In other words, along the inner half of the circumferences of the innermost row of tubes, and in the zone where the centerline circle passes from tube to tube.

Detailed Description Text - DETX (116):
Having thus analyzed the mechanical forces within the substrate, additional analyses may be made of the flow of a fluid through the **membrane** and, thereafter, through the interstices between the solid substances of which the porous substrate is composed. These phenomena are described in a later portion of this specification.

Detailed Description Text - DETX (117):
It is thus seen that the **core** constitutes a system in which three separate phases exist, namely, (1) a continuous solid phase through which (2) a continuous aqueous phase passes, and, (3) the **membrane**. In some cases there is a discontinuity in the liquid system at the point at which a portion of the pressurized feed liquid passes into the semipermeable **membrane,** as will be explained in the next section. If such a discontinuity exists for high rejection **membranes,** such is not the case for ultrafiltration **membranes**.

Therefore, the fluid system may be considered to consist of (1) a pressurized aqueous mixture, (2) a **membrane** acting, in some ways, like an orifice plate, (3) a series of labyrinth passages and, (4) a low pressure collecting duct for the aqueous phase passing through the system.

Detailed Description Text - DETX (118):
Having thus segregated the four different zones of the system, we next turn to a description of the nature of **membranes** and the passage of water through them. **Membranes** normally consist of a skin measuring approximately 0.25 microns in depth, supported by a spongy layer approximately 100 microns in depth. The flow velocity or flux through a **membrane** in my device is given by the following equation:

Detailed Description Text - DETX (124):
k.sub.m =**membrane** constant (cm.sup.3 /gm/sec)

Detailed Description Text - DETX (125):
For my device, the value of k.sub.m will vary from 1 to 5.times.10.sup.-8 cm.sup.3 /gm/sec, for **membranes** with a nominal rejection between 98% and 80%.

Detailed Description Text - DETX (126):
In reverse osmosis (as contrasted with ultrafiltration), a widely held theory suggests that the process of the passage of water through the skin of a cellulose acetate **membrane** involves molecular phenomena in which water molecules associate with acetate groups, and then migrate progressively from one acetate group to another, driven by the net pressure differential (v/km), until they emerge into the open, spongy layer beneath the skin.

Detailed Description Text - DETX (127):
Accordingly, unless the value of .DELTA.P.sub.s is significant when compared with P.sub.f -P.sub.p -.DELTA..pi., the entire pressure drop may be thought of as occurring within the **membrane** skin.

Detailed Description Text - DETX (128):
In order to estimate the magnitude of the internal pressure drop within **cores** of various compositions and fluxes, the following analysis is offered:

Detailed Description Text - DETX (129):
The most critical internal flow rate is that which occurs between adjacent tubes in either the row closest to the permeate duct or the first row in which m=6. To determine the magnitude of this flow rate, it is first necessary to estimate the area of **membrane** outboard of the point of closest approach between

adjacent tubes. For a 1 meter length of **core,** this value may be calculated as follows: ##STR3## R.sub.t is the radius of tubes (cm) n.sub.x is the value of n in the row for which the inter-tube flow velocity is being estimated.

Detailed Description Text - DETX (133):
A.sub.e is the area of **membrane** in a meter of **core** outboard of the circle n=x, expressed M.sup.2

Detailed Description Text - DETX (140):
For example, take the **core** represented in the right side of FIG. 27. In this case, the row closest to the center is n=2, in which m=6. There are 198 tubes in rows 3 through 8. Add to this m.sub.2 n.sub.2 /2 or 6.times.2/2=6 extra tubes, making 204 tubes outboard of the circle n=2. Assuming R.sub.t =0.5 and R.sub.1 =1.15, R.sub.2 =2.times.1.15, ##EQU3##

Detailed Description Text - DETX (147):
In a similar manner, the outboard areas, intertube spacing and intertube flow rates were calculated for the other rows of the **core** illustrated in FIG. 27. The results of these calculations are summarized in Table III.

Detailed Description Text - DETX (154):
Nickelson, et al (R-22) measured the viscous resistance for three highly porous candidate **materials** for external pressure RO **cores**.

Detailed Description Text - DETX (156):
sintered polyvinylidene fluoride, 25 micron pore size, .alpha.=2.7.times.10.sup.5 cm.sup.-2

Detailed Description Text - DETX (157):
sintered polyethylene, 10 micron pore size, .alpha.=1.2.times.10.sup.6 cm.sup.-2

Detailed Description Text - DETX (159):
Using these values for .alpha., the value of dP was integrated for the passage of water between adjacent tubes of radius R.sub.t, in row n=2, separated by the distance S.sub.n. These values are also shown in Table III. As can be seen, for an 8 inch **core** with a flux of 1 M.sup.3 /M.sup.2 /day, with these substrates, very little internal pressure drop would occur, even in ultrafiltration applications with twice the flux used in this analysis.

Detailed Description Text - DETX (160):
In the same manner, the viscous resistance coefficient was calculated for

the ceramic **material** used for external pressure **cores,** and for a nominally rated 2 micron, **sintered polyethylene** filter cartridge.

Detailed Description Text - DETX (162):
sintered polyethylene from 2 micron nominal filter, .alpha.=6.2.times.10.sup.8 cm.sup.-2

Detailed Description Text - DETX (163):
external tubular RO ceramic **core,** (0.1 to 0.5 microns) .alpha.=2.1.times.10.sup.12 cm.sup.-2.

Detailed Description Text - DETX (164):
The latter ceramic **material** is far too dense to be considered for even moderate sized, balanced pressure tubular RO **cores**. However, using the 2 micron nominal **polyethylene** and m=5 for n=2, a moderate pressure drop of 0.78 kg/cm.sup.2 was realized for the permeate flowing through the inter-tube zone, as seen in Table III.

Detailed Description Text - DETX (165):
Next, this same analysis was performed for row n=2 of larger **cores,** using m=5 and m=6. The results are shown in Table IV.

Detailed Description Text - DETX (168):
In order to demonstrate the low relative pressure drop in substrates as compared to **membranes,** it is valuable to compare equations 9 and 14.

Detailed Description Text - DETX (172):
to a form subject to analysis by Darcy's equation. The so-called "**membrane** constant" may be replaced with a factor which includes dt, g.sub.c, .alpha. and .mu.. ##EQU7## or,

Detailed Description Text - DETX (174):
As previously noted, values of k.sub.m for my device range from 1 to 5.times.10.sup.-8 cm.sup.3 /gm/sec. For a **membrane** with a flux of 1 M.sup.3 /M.sup.2 /day, k.sub.m =3.4.times.10.sup.-8. It is believed that the thickness of the active layer or skin of the **membrane** is 0.25 microns or 2.5.times.10.sup.-5 cm. Entering this value for dt, we find, ##EQU8##

Detailed Description Text - DETX (175):
As noted above, the values of .alpha. for several available porous substrates range from 2.7.times.10.sup.5 to 6.2.times.10.sup.8 cm.sup.-2. The value of .alpha. for **membranes** is therefore substantially greater than that of

core substrate, further confirming that the vast majority of pressure drop in a properly design balanced pressure tubular RO **core** is in the surface of the **membrane**.

Detailed Description Text - DETX (177):
1. For large **cores** with high fluxes and low feed pressures, it is beneficial to omit row n=1, and to use m=5 for rows n=2 and n=3.

Detailed Description Text - DETX (179):
3. By a judicious balance of the several operational, **material** and design parameters, a range of conditions can be established in which neither (1) high parasitic pressure drops nor (2) high instantaneous pressure drops in the area of the **membrane** occur.

Detailed Description Text - DETX (183):
Each of the first four entries in Table V represent two 8" pressure vessels, six meters long, each containing six **cores** of the type shown in Table I, entry 17. Each **core** is 0.97 meters long, plus couplers, so that each pressure vessel contains 5.8 meters of **core,** the remaining 20 cm. being taken up with connections and space for remixing the feed solution. In this example, the initial feed entered the first pressure vessel with a linear velocity of 0.61 Meters/sec. and left the eighth pressure vessel at 0.33 Meters/sec. Then, using the principle shown in FIG. 26, the diameter of the pressure vessel was decreased from 8" to 6", using a reducer in conjunction with a 180.degree. return. The linear velocity of the feed was thereby

Detailed Description Text - DETX (185):
The next three entries show the feed solution progressing through six pressure vessels of the 6" size, with the linear flow rate dropping from 0.62 to 0.40 Meters/second. Entries 8 and 9 show alternate options for the next stage. With the 5" pressure vessel, the linear velocity was only increased to 0.48 Meters/second and, after passing through only two 5" vessels, it had dropped to 0.41 Meters per second. For reasons of standardization, it is beneficial to limit the total number of possible sizes of **cores**. Therefore, entry 9 shows a more suitable selection for the next stage. In this entry it is seen that the linear velocity increases from 0.40 Meters/second (from the last 6" vessel) to 0.75. After eight pressure vessels, it drops to only 0.43 Meters/second (entry 13).

Detailed Description Text - DETX (190):
Having thus illustrated the fact that not all sizes of pressure vessels provide beneficial results, Table VI shows eleven of the entries previously

given in Table I. In this case, I have shown the ratios of the **membrane** areas and the ratios of linear velocities of the adjacent entries. The minimum and maximum ratios of **membrane** areas are 1.61 and 2.45 and the minimum and maximum ratios of velocities are 1.61 and 2.40. Ratios larger than these would introduce excessive gaps in capabilities for treating feed solutions and, as shown in the case of the 5" vessel (Table II, entry 8), smaller gaps cannot be justified because they do not sufficiently improve treating capacity.

Detailed Description Text - DETX (191):

Tables I and VI are based upon designs in which m is always 6. However, as noted above, for higher fluxes and, especially, for large diameter **cores,** it is beneficial to use **cores** in which m=5 for the central rows. The left half of FIG. 27 shows a **core** in which there is no row n=1, and, for n=2 and n=3, m=5. Nonetheless, the entries in Tables I and VI are substantially correct. The deletion of one to four tubes results in a very small decrease in relative **membrane** area.

Detailed Description Text - DETX (192):

It might appear to be impractical to consider the fabrication of **cores** as large as 48 inches. However, a comparison of the economical considerations will reveal that there is a substantial incentive in producing such a **core**. One conventional external pressure **core has a membrane** area of 0.046 M.sup.2 and a commercial value of 3,450 or US$11.50. One meter of 7-**core** pressure vessel contains 0.356 M.sup.2 of **membrane** with a value of 26,416 or US$88.05. One Meter of 48" **core,** as shown in Table I, entry 43, has 270 M.sup.2 of **membrane** surface or 758 times as much **membrane,** and could replace conventional external pressure **cores** costing 20,035,000 or US$66,800. In addition, each pressure vessel of this size would have the effect of eliminating 758 smaller pressure vessels, and an equivalent reduction in crossover castings (42), return headers (43), retainer flanges (45), permeate collectors (41) and permeate delivery tubes, plus 2,274 pipe couplers (44). A comparable savings in the frames and supports for the pressure vessels is also realized with the larger sizes of **cores**.

Detailed Description Text - DETX (194):

It is also significant to consider the cost effectiveness of the stainless steel employed in the fabrication of the pressure vessels. Table VII shows the comparative relationships of the weight of steel required to house one square meter of **membrane** surface in the various sizes of pressure vessels previously described in Table VI. For comparison, three different designs of conventional external pressure 7-**core** devices are shown at the bottom of Table VII. This table shows that, for a 21/2 inch schedule 40 conventional external pressure

design, 24.2 kg of pressure vessel is required for each meter of **membrane,** whereas only 2.86 kg is required for a 36 inch pressure vessel fabricated in accordance with the principles of my invention.

Detailed Description Text - DETX (197):
In those cases in which a balance of internal pressure drop cannot be established by **core** design and **material** selection, it is possible to introduce additional axial permeate ducts, 93, as shown in FIG. 31.

Detailed Description Text - DETX (198):
In this figure, an 8" **core** is shown with three additional permeate ducts in row n=6, placed 120.degree. apart, and three optional ducts, 94, at intermediate angles in the same row. For very large sizes with high values of .alpha., additional permeate ducts may be provided in rows beyond that shown. It must be recognized, however, that this technique introduces unbalanced mechanical forces in the zone between these axial ducts and the adjacent tubes.

Detailed Description Text - DETX (199):
On installation, the several axial permeate ducts may be coupled directly to the corresponding duct from the adjacent **core**; they may then be interconnected at the first **core** in the pressure vessel. Or, for **cores** in which space limitations would make it difficult to couple more than one duct, the several ducts may be interconnected at each face of each **core,** reducing to one the number of connections required at the time of installation.

Detailed Description Text - DETX (200):
Another way in which a balance in pressure drop can be established is by placing small radial ducts, 95, in the porous substrate, as illustrated in FIG. 32. In such a case, the staggered placement of tubes shown in Table II cannot be used. These ducts may then be placed 60.degree. apart, provided, of course, that m=6 for the entire **core**.

Detailed Description Text - DETX (202):
These ducts can be made in several manners. In one method, small radial rods are placed in the **core** mold prior to casting the **core,** with one end extending outside the mold. These are removed after fabrication, and the resulting holes, 96, plugged. In another effective method, small rods of a water soluble organic substrate, such as high molecular weight **polyethylene** glycol, or an inorganic substance such as NaCl or Na.sub.2 SO.sub.4, are placed in some of the perforations of the permeate duct prior to fabrication of the **core**. When placed in service, the water soluble substrate gradually leaches away, leaving the desired radial permeate duct. In a third method, suitable

for low temperature **core** fabrication methods, a waxy or crystaline substance can form the duct and it may be melted out of the **core** after curing. In all of these cases, it is beneficial to secure the rods in the proper position by wiring or otherwise attaching them to the mandrels forming several of the tubes prior to casting the **core**.

Detailed Description Text - DETX (203):
Since the principle objective of the radial ducts is to increase the ease with which permeate from the outer portions of a **core** reaches the central permeate duct, it is possible to use a small diameter metal tubing, with or without perforations, to assist in withstanding the unbalanced compressional forces generated by the placement of these ducts in the **core** substrate. Such a duct liner would have one or more orifices within the axial permeate duct to facilitate delivering permeate thereto. To prevent the open end of these tubes from becoming plugged during fabrication, a water soluble plug of organic or inorganic substance may be placed in the ends prior to casting.

Detailed Description Text - DETX (204):
For **cores** requiring radial permeate ducts, the number of these ducts required per linear section of **core** increases with the increasing diameter of the **core**. It is not practical to employ radial permeate ducts at intermediate angles. However, this method may be combined with the use of axial permeate ducts, 93, at intermediate angles, as shown at 30.degree., 90.degree., 150.degree., 210.degree., 270.degree. and 330.degree. of FIG. 33.

Detailed Description Text - DETX (205):
Finally, in those cases in which no external **membrane,** 5, is used, and when maximum pumping efficiency is desired, it is desirable to prevent flow of fluid over the external surface of the **core**. This objective is achieved by the installation of an "O" ring, item 97, or other gasket on the outer surface of the **core,** as illustrated in FIG. 33. In this manner, fluid pressure continues to be exerted on the outer surface of the **core,** while all of the fluid flow is directed through the internal tubes. The installation of the **core** is facilitated by the use of molybdenum disulfide powder, or a suitable amorphous lubricant such as a soft grade of petrolatum or silicone base grease.

Detailed Description Text - DETX (210):
R-2. R. E. Lacey & S. Loeb, "Industrial Processing with **Membranes**", Wiley-Interscience, a Div. of John Wiley & Sons, Inc., New York, (1972)

Detailed Description Text - DETX (211):
R-3. S. Kinura, H. Ohya, S. Suzuki, "Reverse Osmosis Systems, **Membrane**

Separation Technology", Shokuhin Kogyo Gijutsu Ohosakai, (Food Industry Technology Research Association of Tokyo) (1973)

Detailed Description Text - DETX (212):
R-4. Joseph W. McCutchan and Douglas N. Bennion, "Saline Water Demineralization by Means of a Semipermeable **Membrane**" Saline Water Research Progress Summary, Jan. 1, 1970-Dec. 31, 1970, Water Resources Center Desalination Report No. 40, School of Engineering and Applied Science, University of California at Los Angeles, p.p. 1-10

Detailed Description Text - DETX (213):
R-5. Dieter Landolt, "Interfacial Phenomena on Reverse Osmosis **Membranes**", ibid p.p. 23-25.

Detailed Description Text - DETX (216):
R-8. J. M. Jackson & D. Landolt, "About the Mechanism of Formation of Iron Hydroxide Fouling Layers on Reverse Osmosis **Membrane**", Water Resources Center Desalination Report No. 50, September 1972, School of Engineering and Applied Science, University of California at Los Angeles.

Detailed Description Text - DETX (218):
R-10. J. W. McCutchan, D. Antoniuk, G. Chakrabarti, M. Chan, V. Goel, N. K. Patel & E. Selover, "Saline Water Demineralization by Means of a Semipermeable **Membrane**", Water Resources Center Desalination Report No. 57, Progress Report, Jan. 1, 1973 to June 30, 1974, Department of Chemical Engineering, University of California, Berkley and School of Engineering and Applied Science, University of California, Los Angeles. p.p. 55-68

Detailed Description Text - DETX (222):
R-14. J. W. McCutchan, D. Antoniuk, V. Goel, M. Chan, M. B. Kim-E, R. Reddy & E. Selover, "Saline Water Demineralization by Means of a Semipermeable **Membrane**; Firebaugh Agricultural Wastewater Desalting", Water Resources Center Desalination Report No. 62, Progress Report, July 1, 1974-June 30, 1975, Sea Water Conversion Laboratory, University of California, Berkeley and School of Engineering and Applied Science, University of California, Los Angeles, p.p. 25-34.

Detailed Description Text - DETX (224):
R-16. "Further Research on Cellulose Acetate **Membranes**", ibid p.p. 40-47

Detailed Description Text - DETX (230):
R-22. Nickelson, Birkhimer, Coverdell, Lai and Wang, "**Membranes** for Reverse

Osmosis by Direct Casting on Porous Supports", U.S. Dept. of the Interior, Office of Saline Water, R & D Progress Report 520, March 1970.

Detailed Description Text - DETX (235):
C-4. "**Membrane** Separations for the Dairy Industry", Bulletin FS-4 Fluid Sciences Division, Universal Oil Products.

Detailed Description Text - DETX (240):
C-9. "Ultrafiltration Westinghouse **Membrane** Systems . . . End Paint Loss and Water Pollution Problems", Bulletin SA 471-2, ibid.

Detailed Description Text - DETX (241):
C-10. "Reverse Osmosis Westinghouse **Membrane** Systems Cut Soluble Oil Costs", Bulletin SA 471-3, ibid.

Detailed Description Text - DETX (242):
C-11. "Reverse Osmosis & Ultrafiltration Westinghouse **Membrane** Systems recover Valuable Byproducts from Cheese Whey", Bulletin SA 471-4, ibid.

Detailed Description Paragraph Table - DETL (1):
TABLE I

___ **Core**
sizes, numbers of internal tubes, sizes of internal tubes **membrane** areas, crossections and linear velocities Approx. Approx. Total High Flow rate at Nominal Number Approx. Max. max. Area **membrane** pressure 0.38 M/sec or pipe Pipe of I.D. outer internal Ratio inner and cross- 1.26 ft/sec. Entry Size, Pipe I.D., Internal of tubes, **membranes** **membrane** inner/ outer section, liters/ M.sup.3 / No. inches Schedule (cm) tubes (cm) (M.sup.2 /M) (M.sup.2 /M) outer (M.sup.2 /M) (cm.sup.2) min day

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___ 1
11/2" 5S 4.50 6 1.2 0.13 0.23 1.8 0.36 9.48 21.0 31.1 2 2" 5S 5.70 18 1.0 0.17 0.57 3.4 0.79 17.6 40.0 57.8 3 21/2" 5S 6.88 18 1.2 0.20 0.68 3.3 0.88 25.7 58.6 84.4 4 3" 5S 8.47 18 1.5 0.25 0.84 3.3 1.09 37.0 84.4 122 5 3" 5S 8.47 36 1.05 0.25 1.19 4.7 1.44 36.4 82.9 119 6 3" 40 7.79 36 1.0 0.24 1.13 4.7 1.36 33.0 75.3 109 7 31/2" 10S 9.01 36 1.2 0.29 1.36 4.6 1.65 46.6 106 153 8 31/2 40 9.01 36 1.2 0.27 1.36 5.0 1.63 46.2 105 152 9 4" 40 10.23 36 1.4 0.31 1.58 5.1 1.89 61.7 140 203 10 4" 40 10.23 60 1.0 0.31 1.89 6.1 2.19 53.4 122 175 11 4" 40 10.23 60 1.0 -- 1.89 -- 1.89 47.1 107 155 12 5" 40 12.82 60 1.3 0.39 2.45 6.3 2.84 87.6 200 288 13 5" 40 12.82 90 1.0 0.39 2.83 7.3 3.22 83.3 190 273 14 5" 40 90 1.05 -- 2.97 -- 2.97 77.9 178 256 15

6" 40 15.41 90 1.2 0.47 3.39 7.2 3.86 111 254 366 16 6" 40 15.41 126 1.05 -- 4.16 -- 4.16 109 249 358 17 8" 40 20.27 168 1.2 0.63 6.33 10.1 6.96 203 461 665 18 8" 40 20.27 162 1.2 -- 6.10 -- 6.10 183 417 602 19 8" 40 20.27 210 1.05 -- 6.93 -- 6.93 181 415 597 20 8" 40 20.27 264 0.93 -- 8.29 -- 8.29 179 409 589 21 8" 40 20.27 324 0.83 -- 8.45 -- 8.45 175 400 576 22 8" 40 20.27 390 0.75 -- 9.19 -- 9.19 172 395 566 23 8" 40 20.27 462 0.68 -- 9.87 -- 9.87 167 383 551 24 8" 40 20.27 540 0.60 -- 10.18 -- 10.2 153 348 501 25 8" 40 20.27 624 0.55 -- 10.78 -- 10.8 148 338 487 26 8" 40 20.27 714 0.50 -- 11.21 -- 11.2 140 320 460 27 10" 40 25.5 390 1.0 12.25 -- 12.3 306 698 1,006 28 12" 40 30.3 540 1.0 -- 16.96 -- 17.0 424 967 1,392 29 12" 40 30.3 624 0.93 -- 18.23 -- 18.2 424 966 1,392 30 12" 40 30.3 714 0.86 -- 19.29 -- 19.3 415 946 1,362 31 14" 40 33.3 624 1.0 -- 19.60 -- 19.6 490 1,117 1,609 32 14" 40 33.3 714 0.95 -- 21.31 -- 21.3 506 1,154 1,661 33 16" 40 38.1 912 0.98 -- 28.08 -- 28.1 688 1,568 2,258 34 18" 40 42.9 1134 1.0 -- 35.62 -- 35.6 891 2,031 2,924 35 20" 40 47.6 1380 1.0 -- 43.35 -- 43.4 1084 2,471 3,558 36 22" 20 54.0 1794 1.0 -- 56.36 -- 56.4 1409 3,213 4,626 37 22" 60 51.4 1650 1.0 -- 51.84 -- 51.8 1296 2,955 4,255 38 24" 40 57.5 1944 1.0 -- 61.07 -- 61.1 1527 3,481 5,013 39 28" 30 67.9 2784 1.0 -- 87.46 -- 87.5 2187 4,985 7,179 40 32" 40 77.8 3564 1.0 -- 112 -- 112 2799 6,382 9,190 41 36" 40 87.6 4674 1.0 -- 147 -- 147 3670 8,370 12,052 42 42" 80S 104.1 6480 1.0 -- 204 -- 204 5089 11,600 16,700 43 48" 80S 119.4 8580 1.0 -- 270 -- 270 6739 15,400 22,100 44 21/2" 5S 6.88 7 1.600 0.356 -- 0.356 23.3 53.2 76.6 45 21/2" 40 6.27 7 1.600 0.356 -- 0.356 17.0 38.9 56.0 46 19 1.34 -- 0.76 0.76 25.4 57.9 83.3

Entries 44 and 45 represent the standard ROpak 7 **core** design. Entry 46 represents the standard PattersonCandy design.

Detailed Description Paragraph Table - DETL (3):
TABLE II ______________________________ Number of internal tubular
surfaces per row and per **core,** angular spacing and location of first tube in each row., upon condition in which m = 6.* Angular Number of Total number Location of spacing of Row tubes in of tubes in first tube tubes in number, (n) row, (6n) **core,** (X) in row n. row n, (Y)
______________________________ 1 6 6 0.degree. 60.degree. 2 12 18 15.degree. 30.degree. 3 18 36 0.degree. 20.degree. 4 24 60 7.5.degree. 15.degree. 5 30 90 0.degree. 12.degree. 6 36 126 5.degree. 10.degree. 7 42 168 0.degree. 8.57.degree. 8 48 216 3.75.degree. 7.5.degree. 9 54 270 0.degree. 6.67.degree. 10 60 330 3.degree. 6.degree. 11 66 396 0.degree. 5.45.degree. 12 72 468 2.5.degree. 5.degree. 13 78 546 0.degree.

4.62.degree. 14 84 630 2.14.degree. 4.29.degree. 15 90 720 0.degree. 4.degree. 16 96 816 1.88.degree. 3.75.degree. 17 102 918 0.degree. 3.53.degree. 18 108 1026 1.67.degree. 3.33.degree. 19 114 1140 0.degree. 3.16.degree. 20 120 1260 1.5.degree. 3.degree. 21 126 1386 0.degree. 2.86.degree. 22 132 1518 1.36.degree. 2.73.degree. 23 138 1656 0.degree. 2.61.degree. 24 144 1800 1.25.degree. 2.5.degree. 25 150 1950 0.degree. 2.4.degree. 30 180 2790 1..degree. 2.degree. 34 204 3570 0.88.degree. 1.76.degree. 35 210 3780 0.degree. 1.71.degree. 39 234 4680 0.degree. 1.54.degree. 40 240 4920 0.75.degree. 1.5.degree. 45 270 6210 0.degree. 1.33.degree. 46 276 6486 0.65.degree. 1.30.degree. 50 300 7650 0.6.degree. 1.2.degree. ____ *number of tubes in row n is 6n since, for this table, m = 6. Equation for total number of tubes; ##STR1## Equation for spacing of tubes; ##STR2## Location of first tube on even numbered rows = Y/2 In practive, it is prefereble to place only 5 tubes in row n = 1. In such cases the angular spacing is 72.degree. and the total number of **cores** is - 1. In other cases, the row n = 1 is omitted, and the total number of tubes is X - 6. When row n = 1 is omitted and m = 5 for row n = 2, the angular displacement for row n = 2 is 36.degree. and the total number of tubes is X - 8.

Detailed Description Paragraph Table - DETL (4):
TABLE III

___

Internal pressure drops for 8" **cores,** n = 2 to 8; m = 5 or 6. ##STR4## out board **membrane** V (ml/cm.sup.2 /sec polyvinylidine **polyethylene,** ceramic **polyethylene,** ceramic n m area (M.sup.2 /M) S.sub.n (cm) or cm/sec) fluoride, 25.mu. 10.mu. 1.mu. 2.mu. nominal 0.1-0.5.mu.

___ 2 6
6.41 0.191 0.323 0.00052 0.0023 0.0069 1.19 4,000 3 6 5.94 0.198 0.193 0.00032 0.0014 0.0043 0.73 2,500 2 5 6.20 0.421 0.170 0.00034 0.0015 0.0045 0.78 2,600 3 5 5.89 0.434 0.052 0.00011 0.00049 0.0015 0.25 847 4 6 5.28 0.200 0.127 0.00021 0.00095 0.0028 0.49 1,600 5 6 4.43 0.202 0.085 6 6 3.39 0.203 0.054 7 6 2.17 0.203 0.030 8 6 0.75 0.203 0.0009

___

Detailed Description Paragraph Table - DETL (5):
TABLE IV

___

Internal pressure drops for various **core** sizes, n = 2; m = 5 or 6 Internal ##STR5## flow rate, V, polyvinylidine Nominal Pipe Outboard **Membrane** (ml/cm.sup.2 /sec fluoride **polyethylene** ceramic **polyethylene** Size, inches m n Area (M.sup.2 /M) S.sub.n (cm) or cm/sec) 25.mu. 10.mu. 1.mu. 2.mu. nominal

---

___ 8" 6
2 6.41 0.191 0.32 0.00052 0.00023 0.0069 1.19 8" 5 2 6.20 0.421 0.17 0.00034 0.00015 0.00046 0.73 12" 6 2 16.8 0.191 0.84 0.0014 0.0063 0.019 3.24 12" 5 2 16.7 0.421 0.46 0.00091 0.0041 0.012 2.10 18" 6 2 34.4 0.191 1.8 0.0029 0.013 0.039 6.7 18" 5 2 34.4 0.421 0.97 0.0019 0.0086 0.026 4.4 24" 6 2 60.9 0.191 3.0 0.0049 0.022 0.066 11 24" 5 2 60.9 0.421 1.7 0.0033 0.015 0.045 7.5 36" 6 2 146.6 0.191 7.4 0.012 0.054 0.161 27 36" 5 2 146.6 0.421 4.0 0.008 0.036 0.108 18 48" 6 2 269.3 0.191 14. 0.0022 0.098 0.293 50 48" 5 2 269.3 0.421 7.4 0.015 0.066 0.198 34

___

Detailed Description Paragraph Table - DETL (6):
TABLE V

___ Cell
Considerations Cumu- En- Size lative try and M.sup.2 .times. Flux % Conc. Per- No. Q TDS V P .DELTA.P No. = Perm. TDS Q TDS V P .DELTA.P Perm. Ratio meate

---

___ 1 2
3 4 5 6 7 8 1,000 762 762 537 537 409 409 293 500 647 647 902 902 1167 1167 1601 0.61 0.47 0.47 0.33 0.62 0.47 0.47 0.41 70 69.9 69.9 69.85 69.85 69.75 69.75 69.42 .06 x .03 x .06 x .03 x ##STR6## 881 881 647 647 473 473 347 564 564 756 756 1017 1017 1364 1364 0.54 0.54 0.40 0.40 0.54 0.54 .40 0.48 69.94 69.94 69.87 69.87 69.79 69.79 69.72 69.72 x .04 x .02 x .04 x 5.5 5.5 5.5 5.5 5.5 5.5 5.6 1.14 1.31 1.55 1.86 2.11 2.44 2.88 119 238 353 463 527 591 653 9 10 11 12 13 310 310 236 236 236 1518 1518 1966 1966 1966 0.67 0.67 0.51 0.51 0.83 69.12 69.12 69.01 69.01 69.01 x .06 x .04 0.10 ##STR7## 347 273 273 200 213 1364 1712 1712 2300 2167 0.75 0.59 0.59 0.43 0.75 69.72 69.06 69.06 68.97 68.91 .06 x .05 x x 5.5 5.5 5.5 5.6 3.23 3.66 4.24 5.0 690 727 764 800 14 15 16 17 18 19 20 21 22 23 154 154 108 108 90 90 68 68 52 52 2950 2950 4129 4129 4905 4905 6390 6390 8249 8249 0.54 0.54 0.71 1.32 1.10 1.10 0.83 0.83 0.64 0.64 68.85 68.85 68.63 68.63 68.09 68.09 67.60 67.60 67.38 x .04 x .20 x .26 x .15 x .05 ##STR8## 200 132 132 102 102 79 79 57 57 47 2300 3414 3414 4358 4358 5547 5547 7567 7567 9070 0.70 0.46

0.87 1.25 1.25 0.97 .97 0.70 0.70 0.57 68.97 68.81 68.81 68.43 68.43 67.83 67.83 67.45 67.45 67.33 .12 x .18 x .34 x .23 x .07 x 5.4 5.6 5.7 5.7 5.8 6.0 6.1 6.2 6.3 6.49 7.58 9.26 9.80 11.11 12.66 14.71 17.54 19.23 21.28 846 868 892 898 910 921 932 943 948

___ 953

Q is Quantity of feed or concentrate in M.sup.3 /day: TDG is Total Disolved Solids in ppm: V is linear velocity of fluid in Meters per second: P is pressure in Kg/cm.sup.2 : .DELTA.P is pressure drop in kg/cm.sup.2 : Flux is given in M.sup.3 /M.sup.2 of **membrane** surface: Perm is quantity of permeate in M.sup.3 /day: % Perm. is percent permeation which is the same as 100% minus percent rejection: Conc. ratio is concentration ratio, or Volume of initial feed divided volume of concentrate at each stage of the calculations: Cumulative Permeate is the volume of permeate from a given plus the volume of permeate from all uppe entries.

Detailed Description Paragraph Table - DETL (7):
TABLE VI

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Practical Sizes, Area Ratios and Velocity Ratios Flow Rate, Nominal Area Ratio, M.sup.3 /day at Velocity Ratio, Pipe Size Number of Approx. **Membrane** area, lower entry/ 0.38 M/sec. or lower entry/ (inches) Pipe Schedule tubes I.D., cm. M.sup.2 /M upper entry 1.25 ft/sec. upper entry

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11/2" 5S 6 1.2 0.36 31.1 1.86 2" 5S 18 1.0 0.74 2.06 57.8 1.89 3" 40 36 1.0 1.36 1.61 109 1.61 4" 40 60 1.0 2.19 1.90 175 2.05 6" 40 126 1.05 4.16 1.67 358 1.67 8" 40 210 1.05 6.93 2.45 597 2.33 12" 40 540 1.0 17.0 2.09 1,390 2.10 18" 40 1134 1.0 35.6 1.72 2,920 1.71 24" 40 1944 1.0 61.1 2.40 5,010 2.40 36" 40 4674 1.0 147 1.84 12,000 1.83 48" 80S 8580 1.0 270 22,100

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Claims Text - CLTX (1):

1. A tubular **membrane** filtration device in which a semiporous **core** has one or more internal passages with semipermeable **membrane** coated surfaces and one or more internal permeate ducts without **membrane, said core** being positioned in an outer pressure vessel, each permeate duct communicating with the outside of said pressure vessel to facilitate the discharge of permate, and in which two different grades of semiporous substances are employed, the semiporous substance surrounding each permeate duct for a depth of at least 0.5

centimeters possessing a relatively low void volume, a relatively high bulk modulus and/or a relatively small particle size, and in which the balance of the **core** is composed of a different semiporous substance with a relatively high void volume, a relatively low bulk modulus and/or a relatively large particle size.

Claims Text - CLTX (2):
2. The device of claim 1 in which coupling devices are permanently sealed into the semiporous **core**.

Claims Text - CLTX (3):
3. The device of claim 1 in which the semiporous **core is a material** selected from the group consisting of a ceramic, **sintered** glass, **sintered** plastic, foamed plastic or **sintered** metal.

Claims Text - CLTX (4):
4. The device of claim 1 in which the semiporous **core** is composed of a frit of fused or otherwise consolidated silica, sand, feldspar, clay, diatomaceous earth, or other inorganic mineral or fossil substance.

Claims Text - CLTX (5):
5. The device of claim 1 in which one or more like **cores** are installed in series array within a cylindrical pressure vessel, said pressure vessel terminating in generally U-shaped tubing returns, such tubing returns having installed sections of pipe extending through the wall of the U-shaped portion thereof, each such pipe section being coupled directly to the permeate duct of the terminal **core** in a series array of **cores**.

Claims Text - CLTX (6):
6. The device of claim 1 in which each internal permeate duct contains a perforated metal liner having nonperforate end portions extending beyond the ends of the **core,** said end portions having fittings for connection to a like liner or to a permeate removal tube, a series array of like **cores** being installed in pipe-like pressure vessels connected by generally U-shaped tubing returns, and in which tubing returns there are installed sections of permeate removal tubing so positioned that they couple directly to the permeate duct of the terminal **core** in the string of **cores** within the corresponding pressure vessel.

Claims Text - CLTX (7):
7. The device of claim 1 in which said installed sections of tubing are coupled via a swivel joint so as to permit rotation of said string of **cores**

during operation.

Claims Text - CLTX (8):
8. The device of claim 1 in which said swivel joint is coupled to an impeller used to increase the angular velocity of said permeate duct liner and associated **cores** during operation.

Claims Text - CLTX (9):
9. The device of claim 1 in which the semiporous **core** has a circular cross-section and which all **membrane** coated internal passages have circular cross-sections with radii r, and in which the axes of the **membrane** coated passages are distributed uniformly on each of a series of concentric circles n, designated by integers progressing from 1 as their radii increase, and in which the number of tubular passages on each such circle is n times m, where m is equal to 0, 5 or 6 when n equals 1 or 2; and where m is 5 or 6 when n equals 3 or more, and where the value of r and the radii of the concentric circles are fixed in such a way that the space between the nearest approach of tubular passages is not less than 0.5 mm.

Claims Text - CLTX (10):
10. The device of claim 1 in which the semiporous **core** has a circular cross-section and in which all **membrane** coated internal passages have circular cross-sections with radii r, and in which the axes of the **membrane** coated passages are distributed uniformly on each of a series of concentric circles n, designated by integers progressing from 1 as their radii increase, and in which the number of tubular passages on each such circle is n times m, where m equals 0.5 and 6, and where the value of r and the radii of the concentric circles are fixed in such a way that the space between the nearest approach of internal passages is not less than 0.5 mm, and in which auxiliary permeate ducts radiate laterally from the central axial permeate duct through the space between internal **membrane** coated passages.

Claims Text - CLTX (11):
11. The device of claim 1 in which a plurality of like **cores** are connected in a series string by couplers, and in which the couplers between **cores** in said series string create a spacing of at least 1 centimeter.

Claims Text - CLTX (12):
12. A tubular molecular filtration device in which a semiporous **core** has one or more internal passages with semipermeable **membrane** coated surfaces and at least one internal permeate duct without **membrane,** the outer surface and end faces of said **core** being fluid impervious, said **core** being positioned in an

outer pressure vessel, one end of said permeate duct communicating with the outside of said pressure vessel to enable it to discharge permeate, the other end of said duct being either plugged to prevent intrusion of feed solution or connected to other similar **cores** in a series string, the permeate duct of the terminal **core** in the series string being plugged to prevent intrusion of feed solution, and in which the **cores** are fitted with means for interconnecting, a **core** or string of **cores** being installed in pressure vessels terminating in 180.degree. tubing returns through which tubing returns there are installed sections of permeate removal tubing so positioned that they may be coupled directly to the permeate duct of said **core** or terminal **core** in a string of **cores,** the diameter of the **cores** and pressure vessels being staged progressively smaller as the feed solution passes from the feed to the concentrate end of the bank of **core**-containing pressure vessels so that the velocity of the solution past the **membrane** surfaces may be controlled in the range above that at which fouling occurs and below that at which pumping efficiency decreases.

Claims Text - CLTX (13):

13. The device of claim 12 wherein said staging in diameters of **cores** and pressure vessels is facilitated by the use of tubing reducers connected between pressure vessels and 180.degree. tubing returns at appropriate places within said bank so that the linear flow rates are increased at the points of transition from one diameter to the next smaller diameter.

Claims Text - CLTX (14):

14. A method for carrying out reverse osmosis or ultrafiltration by using a molecular filtration device consisting of a semiporous **core** with semipermeable **membrane** on the outer profile, one or more internal passages with semipermeable **membrane** coated surfaces and one or more internal permeate ducts without **membrane, and wherein said core** is fitted with means for interconnecting, said **core** or a string of **cores** installed in pressure vessels terminating in 180 degree tubing returns and in which tubing returns are installed sections of pipe or tubing so positioned that they may be coupled directly to said **core** or terminal **core** in a string of **cores,** the diameter of the **cores** and pressure vessels being staged progressively smaller as the feed solution passes from the feed to the concentrate end of the **core** bank so that the velocity of the solution past the **membrane** surfaces may be controlled within the ranges in which the fouling occurs and in which pumping efficiency decreases, said staging in diameters of **cores** and pressure vessels being facilitated by the use of tubing reducers connected between pressure vessels and bent tubing returns at appropriate places within the **core** bank so that the linear flow rates are increased at the points of transition from one diameter to the next smaller

diameter, said permeate ducts equipped with suitable connectors, with all **materials** employed in said **core,** connectors, seals and allied parts being composed of organic substances, in which method a radioactive or toxic substance is treated and concentrated, and in which, after exhaustion of the **core** or termination of the process, the residual **core,** and all ot its attached parts are decomposed by a thermal or chemical process, thereby yielding the minimum weight and volume of residual inorganic ash.

Claims Text - CLTX (15):
15. In a tubular **membrane** filtration device in which a semiporous **core** has one or more internal passages with semipermeable **membrane** coated surfaces and one or more internal permeate ducts without **membrane, said core** being positioned in an outer pressure vessel, each permeate duct communicating with the outside of said pressure vessel to facilitate the discharge of permeate, the improvement wherein the semiporous **core is a material** having a viscous resistance coefficient in the range of from about 1.times.10.sup.5 /cm.sup.2 to not more than 10.sup.9 /cm.sup.2 and wherein the viscous resistance coefficient of said semipermeable **membrane** is substantially greater than that of said **core,** whereby the majority of the pressure drop between said internal passages and said permeate ducts occurs at the surface of said **membrane** with little internal pressure drop in said **core,** and wherein said pressure vessel comprises a set of serially connected vessel pipes each containing one or more of said **cores,** and wherein the successive vessel pipes and the **cores** contained there within are of progressively smaller diameter.

Claims Text - CLTX (16):
16. A **core** for a pressure balanced filtration system, comprising:

Claims Text - CLTX (17):
a generally cylindrical rigid body of porous **material,** said body having at least one internal passage extending therethrough, each such internal passage having a semipermeable **membrane** on its surface, said body also having at least one **membrane**-free duct extending therethrough, swaid body being adapted for mounting within an outer vessel with a space therebetween, so that as a feed solution flows through said internal passages and through the space between said body and the outer vessel, the radially outward forces exerted by said feed solution flowing through said internal passages will be balanced by the radially inward forces of the feed solution flowing through said space between said body and said vessel, in which:

Claims Text - CLTX (19):
17. In a semiporous **core** for a tubular molecular filtration system, said

core having one or more semipermeable **membrane** lined internal passages adapted for feedthrough of an input fluid and having at least one internal permeate duct without **membrane,** said permeate duct being connectable to an outlet of said filtration system at a pressure substantially less than the pressure of said inlet fluid so that a compressional force imbalance will exist in the portion of the semiporous **core** surrounding said permeate duct, the improvement wherein:

Claims Text - CLTX (20):

said **core** is formed of two different porous **materials, said core** portion surrounding said permeate duct and subjected to said compressional force imbalance being formed of a first, relatively higher density porous **material,** the remainder of said **core** being formed of a relatively less dense porous **material**.